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CONTENTS

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TWO ELECTRIC GENERATORS SUITABLE FOR THE MEASUREMENT OF MAGNETIC INTENSITIES AND THEIR VARIATIONS AND FOR OTHER PURPOSES*

BY S. J. BARNETT

Introduction

Rotating coils with their terminals connected through commutators or slip rings to electric measuring devices have often been used for measuring or detecting magnetic intensities. For high sensitivity, it is desirable that the rotating coil be wound of very fine wire, which is a disadvantage, particularly at high speeds; and mechanical and electrical difficulties are often caused by the sliding contacts with the brushes.

It occurred to me a long time ago that all the difficulties could be avoided by using, in place of the common devices, a fixed coil with a large constant and a simple toroidal ring of low resistance rotating about a diameter inside the coil. When Dr. F. G. Dunnington was working on the determination of e/m for the electron in the Norman Bridge Laboratory nine or ten years ago, he was having some of the usual difficulties with the rotating coil, and I suggested that he use the rotating ring and fixed coil. He tried the arrangement, but reported to me that he could get no electromotive force; and he returned to the rotating coil. Though much surprised at this result, I did not look farther into the matter until a few years ago. Two years ago last summer I designed and had constructed suitable apparatus for testing this method, and also another closely related method, in which the ring is replaced by a group of magnetic rods. Both of these in preliminary tests immediately worked as predicted. Only very recently, however, has it been feasible to make detailed observations.

Theory of the rotating-ring generator

The rotating ring method will be considered first. For definiteness it will be supposed to be applied to the measurement or detection of a vertical

*A paper read before the American Physical Society, January 12, 1946.

intensity V, for example that of the vertical component of the Earth's magnetic intensity. Changes suitable for other cases will immediately suggest themselves.

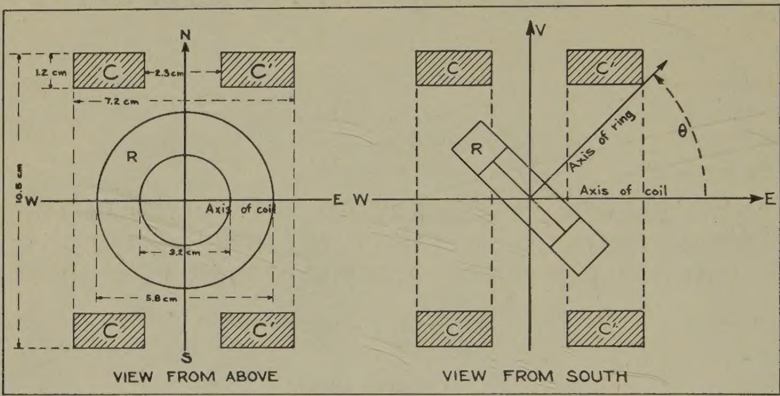


FIG. 1—DIAGRAMS OF ROTATING RING GENERATOR, INCLUDING HELMHOLTZ-COIL SYSTEM CC′

A Helmholtz-coil system CC' [Figs. 1(A) and 1(B)] is mounted with its axis horizontal and in the magnetic prime-vertical. A circular toroidal conducting ring R is mounted rigidly and symmetrically on a cylindrical brass rod with its axis SN along a diameter of the ring, horizontal, and in the magnetic meridian. The center of the ring is made to coincide with that of the Helmholtz pair. The ring is rotated uniformly about the axis SN, and the emf E developed in the Helmholtz coil is measured with a high-impedance instrument.

(A) *The Thin Ring*—First suppose that the ring is thin, both axially and radially, so that eddy currents are negligible. Let V denote the vertical intensity of the magnetic field, upward in Figure 1(B) for convenience, θ the angle made by the axis of the ring with the axis of the coil, and A the mean area of the ring.

Then the magnetic flux through the ring is $\varphi_r = AV \sin \theta$.

Let the angular velocity in revolutions per second be denoted by f, and in radians per second by $p = 2\pi f$; then the emf induced in the ring is

$$e_r = -(d\varphi_r/dt) = -AVp\cos pt = -E_r \cos pt$$

Let i denote the current in the ring, R its resistance, L its inductance, Z its impedance. Then, if

$$\alpha = \tan^{-1}[(Lp/R) = \beta]$$

$$i = -(pAV/Z)\cos(pt - \alpha) = -\mathrm{I}\cos(pt - \alpha)\ldots\ldots\ldots\ldots(1)$$

a result which is of course well known.

The magnetic moment of the ring is thus

$$m = Ai = -(pA^2V/Z)\cos(pt - \alpha) = -M\cos(pt - \alpha) \ldots\ldots(2)$$

If φ_G denotes the magnetic flux produced by the ring through the Helmholtz coils and G the axial constant of the coils, supposed uniform throughout the region in which the ring rotates, we have

$$\varphi_G = Gm\cos\theta = -(GpA^2V/Z)\cos(pt - \alpha)\cos pt$$

The emf induced in the coils is thus

$$\begin{aligned} e &= -(d\varphi_G/dt) = -(p^2A^2VG/Z)\sin(2pt - \alpha) \\ &= -[p^2A^2VG/R(1 + \beta^2)^{\frac{1}{2}}]\sin(2pt - \alpha) \\ &= -E\sin(2pt - \alpha) \ldots\ldots(3) \end{aligned}$$

According to this formula, E is proportional to the coil constant, to the square of the mean area of the ring, to the magnetic intensity V, and to p^2/Z; and it is harmonic with twice the frequency of rotation. When α is small, so that Z is nearly independent of p, E is proportional to p^2.

(B) *Short-Circuited Rotating Coil*—Suppose the thin ring replaced by a short-circuited closely-wound circular cylindrical coil of n turns of insulated wire with cross-section small enough to prevent the formation of appreciable eddy currents.

If A denotes the total area of the coil, and A' the mean area of a single turn, so that $A = nA'$, and if R denotes its resistance, Z its impedance, L its inductance, Lp its reactance, and β the quantity $(Lp/R) = \tan\alpha$, we again obtain equation (3). For toroids of the same shape and size and total volume of wire, with the same resistivity, the quantities β, α, and E are independent of the cross-section of the wire.

(C) *The Thick Ring*—When the ring is thick eddy currents introduce serious complications. If they are neglected, and if the frequency is so low that the reactance is negligible, the moment of the ring can be obtained as follows when the cross-section of the toroid is rectangular.

The emf around a circle of radius r is

$$e_r = -\pi r^2 Vp\cos pt$$

The current-density at all points of the cylinder of radius r is

$$c_r = e_r/2\pi r\sigma = -(Vpr/2\sigma)\cos pt \ldots\ldots(4)$$

where σ is the resistivity of the ring. If W is the width of the ring, the current through an area Wdr of the cross-section of the ring at the radius r is

$$di_r = c_r W dr = -(pWVr/2\sigma)\, dr \cos pt$$

The moment of the ring is thus

$$m = \int_{r_1}^{r_2} \pi r^2 di_r = -(pWV\pi/8\sigma)(r_2^4 - r_1^4) \cos pt \qquad (5)$$

The emf in the Helmholtz coils is thus

$$\begin{aligned} e &= -d(Gm \cos pt)/dt \\ &= -(p^2 GWV\pi/8\sigma)(r_2^4 - r_1^4) \sin 2\,pt \\ &= -E \sin 2\,pt \qquad (6) \end{aligned}$$

The total current in the ring is

$$i = W \int_{r_1}^{r_2} c_r\, dr = -(pWV/4\sigma)(r_2^2 - r_1^2) \cos pt = -I \cos pt \qquad (7)$$

The mean value of the emf around the ring is

$$\begin{aligned} \overline{e_r} &= [1/(r_2 - r_1)] \int_{r_1}^{r_2} e_r\, dr \\ &= -[\pi V p(r_2^3 - r_1^3)]/3(r_2 - r_1) \cos pt \\ &= -\overline{E_r} \cos pt \qquad (8) \end{aligned}$$

The ratio

$$\overline{E_r}/I = (4\pi\sigma/3W)[(r_2^3 - r_1^3)/(r_2^2 - r_1^2)(r_2 - r_1)] = R \qquad (9)$$

would be the resistance of the ring under the conditions assumed.

When eddy currents cannot be neglected (as they never can be in a thick conducting ring), or when the reactance cannot be neglected, or both, the relation (4) is not entirely valid and the theory becomes very crude. Eddy currents due to the axial thickness of the ring produce an electromotive force opposing (6) and the stream-lines are distorted both by all the eddy currents and by the brass rod and screws passing through parts of the ring in the experimental apparatus. As M. Wien has shown, the inductance of a thick ring is nearly the same when the current-density is independent

of the radius and when it is proportional to the radius, as in (5). We can get a rough approximation to the truth by assuming that the simple formula (3) applies, but that the resistance of the ring is greater than R given by (9), that the inductance L has the value calculated from one of the standard formulae for a thick ring, and that the phase-angle β is less than (Lp/R).

The exact theoretical calculation of the value of E, however, is of relatively slight importance as the instrument can readily be calibrated by experiment.

Experimental arrangements

The dimensions of the rotating ring, which was of aluminum, and those of the Helmholtz coils, are indicated in Figure 1. A photograph of the ring and the brass axle on which it was mounted is given in Figure 2. They were mounted in a rigid box-like structure precisely made from half-inch bakelite and provided with accurately made bearings so arranged that different

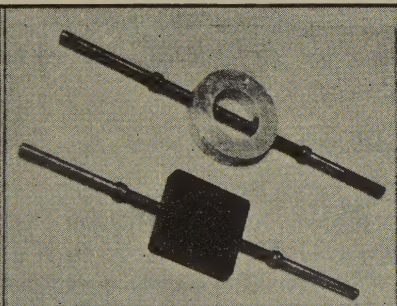


FIG. 2

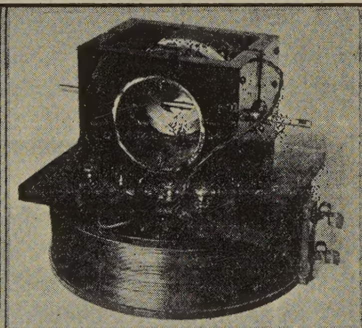


FIG. 3

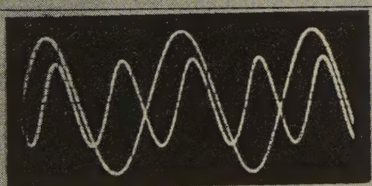


FIG. 4

FIG. 2—ROTATING RING AND AXLE AND ROTATING MAGNETIC SYSTEM AND AXLE

FIG. 3—RING GENERATOR AND ONE OF LARGE COILS FOR PRODUCING EXPERIMENTAL FIELDS

FIG. 4—OSCILLOGRAM OF GENERATOR EMF, FIELD-STRENGTH 134 GAUSSES AT 60 RPS, AND OSCILLOGRAM OF 60-CYCLE-PER-SECOND SINE-WAVE WITH 30 VOLTS RMS APPLIED TO OSCILLOGRAPH TERMINALS

rotating systems could be quickly interchanged. A photograph of the apparatus is given in Figure 3, including one of the large coils for producing the experimental fields (aside from the Earth's field). While the experiments were in progress another and similar coil was kept mounted above the box, the two being symmetrical, or approximately symmetrical, with regard to the center of the rotating system.

The Helmholtz coils originally provided with the instrument were poorly made, but served well enough in the preliminary work, which agreed

as well as could be expected with that done later. For this work two sets of coils were precisely wound on hard-maple bobbins by the Hollywood Transformer Company. All had the approximate dimensions indicated in Figures 1 and 2. One of the pairs was wound with No. 18 SCE copper wire, 165 turns in each coil; the other was wound with No. 36 enamelled copper wire, exactly 11,000 turns in each coil. The constant of this latter pair (in series) was determined experimentally as 22.6×10^3 gauss/emu current; the two pairs, with practically the same dimensions, had constants very nearly proportional to their numbers of turns, so that the constant of the former pair (in series) was approximately $22.6 \times 0.015 = 0.34 \times 10^3$ gauss/emu current. All the detailed work described here, except as otherwise indicated, was done with the coils with the large constant.

The area A of the rotating coil was determined electrically, use being made of the uniform field of a long standard solenoid and a properly calibrated Hibbert magnetic standard, the two halves of the rotating coil being put in series for this purpose. The constant G was likewise determined experimentally, use being made of the same coil, now mounted in the Helmholtz pair. The field-intensity was measured with the help of a short cylindrical coil wound around the aluminum ring, held with its axis coincident with that of the field-producing system.

Experimental results with the aluminum ring

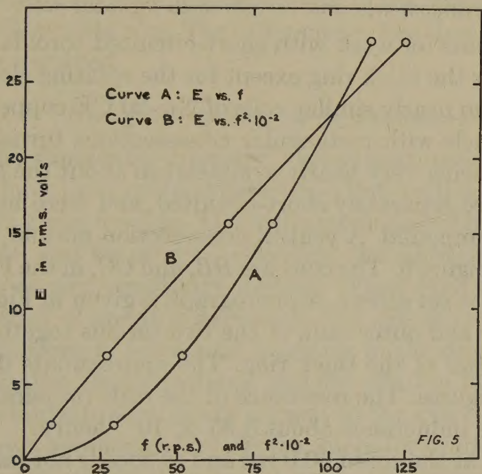
As the theory requires, the emf has exactly twice the frequency of the rotation and its amplitude E is strictly proportional to the field intensity V. The wave-form (Figure 4) is not distinguishable by the eye from a pure sine-curve, and comparison with the sine-wave of a standard oscillator by means of Lissajous figures likewise shows no certain departure from sine-form, though neither the constant of the Helmholtz coils nor the applied field is strictly uniform throughout the region traversed by the moving ring.

An oscillogram of the emf with the ring rotating 60 rps in a magnetic field of strength 134 gausses is given in Figure 4, together with that produced on the same film by impressing a pure sine-wave of frequency 60 cycles per second and magnitude 30 volts rms on the same terminals in another exposure. The ring was direct-driven by a synchronous motor operated from the same mains which produced the 30-volt emf.

Proportionality with G is verified by throwing the coils into parallel, when E has just one-half its value for the series arrangement. By putting the coils in opposition, E is reduced to zero. The way in which E depends on the frequency is exhibited in Figure 5. The curve E versus f is not strictly a parabola, and the curve E versus f^2 is not exactly a straight line, as would be so if the reactance of the ring and eddy currents were negligible.

With the thickness of the ring 1.26 cm, and the inner and outer diameters as given in Figure 1, and with $\sigma = 2.8 \times 10^3$ emu, $R = 25 \times 10^{-6}$ ohm.

(Calculations from the standard formula for a toroid, which assumes the same emf for all radii, gives nearly the same result, namely 24×10^{-6} ohm.) Calculations of the inductance of the ring from Weinstein's formula, which assumes that the current-density is uniform throughout the ring, give about 44 emu; while calculation from Wien's formula which assumes the current-density proportional to the radius, as in (4), gives about 45 emu. Thus $(L/R) = 1.8 \times 10^{-3}$; and at 60 rps, the quantity $\beta \equiv (Lp/R) =$ about 0.7.



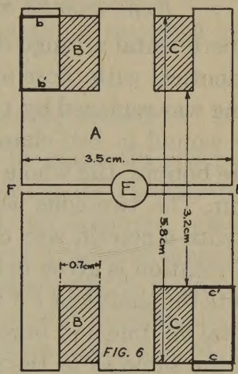


FIG. 5—DEPENDENCE OF E ON FREQUENCY

FIG. 6—CROSS-SECTION NORMAL TO AXIS OF ROTATION, TOROIDAL-COIL ARMATURE

With $V = 245$ gausses, and $p = 2\pi \times 60$, the amplitude I calculated from (7) is 5.9×10^2 amperes. When the reactance Lp is taken crudely into account* this is reduced to 4.8×10^2 amperes. The amplitude $\overline{E}_r$ calculated from (8) is about 0.015 volt, and the power-factor is 0.8, so that the average power dissipated in the ring is about three watts. This would raise the temperature of the ring about 1°C in 18 seconds if there were no losses. No temperature-rise has been observed.

The calculated value of E for $V = 245$, $f = 60$, no reactance and no eddy-currents gives 80 volts, corresponding to the rms-value 57 volts. When the reactance of the ring is taken into account as above this is reduced to 46 volts. The experimental value was 31 volts, the ratio being thus 1.5. Eddy-currents and the necessarily crude treatment of the reactance, together with the crowding of the stream-lines by the brass axle and screws, both referred to above, and the departure of the fields from exact uniformity doubtless account for much of the discrepancy. The resistivity of the

*By substituting for R the quantity $R(1 + \beta^2)^{\frac{1}{2}}$, a process which would not be completely justified even if eddy currents vanished because the presence of inductance destroys the relation (7).

aluminum, moreover, was assumed from the tables, but the variations probable can hardly account for much of the discrepancy.

As to the variation of E with the frequency, the following calculations may be made: With $V = 186$ gausses the values of E at 60 and 29 rps were 23.5 and 6.0 volts (rms), respectively. We have $(60/29)^2 = 4.28$, while $23.5/6.0 = 3.92$. If, however, we multiply the former by the ratio of $(1 + \beta^2)^{\frac{1}{2}}$ for $f = 29$ to $(1 + \beta^2)^{\frac{1}{2}}$ for $f = 60$, we obtain 3.70, which makes the agreement somewhat better.

Experimental arrangements and results with toroidal coils

Experimental arrangements for work with short-circuited toroidal coils were identical with those for the thick ring except for the rotating element. The ring was replaced by two nearly similar coils of No. 20 CE copper wire closely wound in two channels with rectangular cross-sections turned in a bakelite bobbin, the whole being very nearly symmetrical about the axis of rotation. The two coils were separately short-circuited, and were impregnated with a ceresin wax compound. A central cross-section normal to the axis of rotation is given in Figure 6. The coils are BB, and CC, in the Figure; E admits the shaft and FF the set screws. A photograph is given in Figure 7. The total volume and inner and outer radii of the two toroids together are nearly the same as in the case of the thick ring. The approximate dimensions are indicated in the Figures. The resistance of the coils (in parallel) is 0.340 ohm at 23°C, and the inductance about 3.95×10^{-4} henry.

Experiments were made at the speed 60.0 rps and at speeds not far from 29.5 rps, and in fields with strengths 134 gausses and 268 gausses. As required by theory the emf is harmonic with twice the frequency of rotation and is exactly proportional to the field-strength. An oscillogram for 60 rps and 134 gausses is given in Figure 8, together with a 60 cycle-per-second sine-curve with amplitude 30 volts rms.

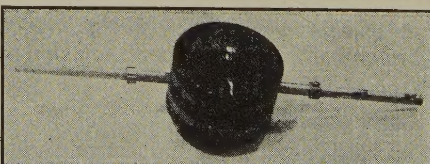


FIG. 7—TOROIDAL-COIL ARMATURE

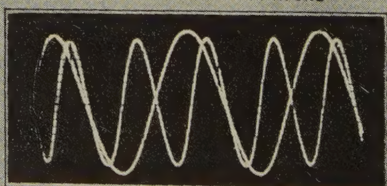


FIG. 8—OSCILLOGRAM OF GENERATOR EMF, FIELD-STRENGTH 134 GAUSSES AT 60 RPS, AND 60-CYCLE-PER-SECOND SINE-CURVE WITH AMPLITUDE 30 VOLTS RMS

At the field-strength 268 gausses $E = 52.0$ volts rms for $f = 60$, and 13.2 volts rms for $f = 29.4$. The values of $(1 + \beta^2)^{\frac{1}{2}}$ for $f = 60$ and $f = 29.4$ are 1.091 and 1.023, respectively. Thus $(52.0/13.2) = 3.94$, while $(60/29.4)^2 \times (1.023/1.091) = 3.91$. The difference is less than the experimental error.

To calculate the theoretical value of E at 268 gausses and $f = 60$ rps the appropriate substitutions must be made in equation (3). We have $G = 22.6 \times 10^3$ gausses per emu current, $A = 1772$ cm^2, $V = 268$ gausses, $p = 2\pi \times 60$, $R = 0.340 \times 10^9$ ohms, $(1 + \beta^2)^{\frac{1}{2}} = 1.091$. These substitutions give $E = 72.9$ volts, corresponding to the rms value 51.7 volts. Experiment gives 52.0 volts rms. The difference is less than might be expected from the errors involved.

Use of the instrument as a vertical-intensity variometer

The horizontal-intensity variometers used in magnetic observatories have long been quite satisfactory; but vertical-intensity variometers have always given trouble. The instrument described here is simple, robust, and reliable, and by proper design and the addition of a suitable amplifier can be given any sensitivity desired. When high sensitivity is required great constancy of speed is necessary, but this offers no serious difficulty today. Fluctuations in horizontal intensity in the direction of the axis of rotation do not alter the indications, and the effect of fluctuations in the component of the horizontal intensity normal to the axis can be automatically neutralized by a supplementary device, such, for example, as that used by Kettering and Scott* in their recent work on electron inertia.

The rotating magnetic-rod generator

General theory—In this generator a group of thin straight parallel rods of highly permeable and but slightly retentive magnetic material, mounted symmetrically normal to the axis of rotation, is substituted for the rotating ring.

Let m denote the moment of the system when its magnetic axis makes the angle $\theta = pt$ with the axis of the coils [and the angle $(90° - \theta)$ with the direction of the field; see Figure 9]. Then the magnetic flux it sends through the coils will be

$$\varphi = Gm \cos pt$$

and the emf induced in the coils will be

$$e = -(d\varphi/dt) \equiv -G[d(m \cos pt)/dt] \qquad \text{(10)}$$

or

$$e = Gmp \sin pt - G(dm/dt) \cos pt \qquad \text{(11)}$$

*Phys. Rev., 66, 257 (1944).

The first term of (11) is an emf due entirely to the motion of the magnet; the second term is an emf due entirely to the rate of change of the moment.

Weak fields—Probably the most important case is that in which the field is so weak and the magnetic system such that hysteresis vanishes and saturation is not approached.

In this case

$$m = CV \sin pt = M \sin pt. \qquad (12)$$

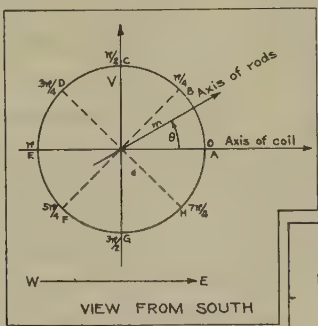


FIG. 9

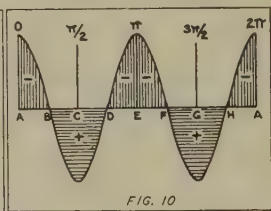


FIG. 10

FIG. 9—DIAGRAM FOR ROTATING MAGNETIC-ROD GENERATOR

FIG. 10—EMF FOR WEAK FIELDS, MAGNETIC-ROD GENERATOR, VERSUS POSITION-ANGLE OF MAGNETIC AXIS

FIG. 11—RANGE OF EMF VERSUS INTENSITY OF APPLIED FIELD UP TO 6.25 GAUSSES

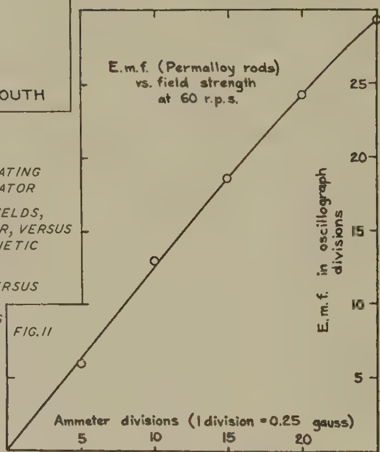


FIG. 11

where C is constant and $CV = M$ is the maximum moment, attained when the positive direction along the rods is in the direction of the field.

In this case (10) gives

$$e = -GMp \cos 2\,pt = -E \cos 2\,pt. \qquad (13)$$

The emf is thus harmonic, its frequency is twice the frequency of rotation, and its amplitude is proportional to G, to the strength of the magnetic field, and to the frequency of rotation. Negative maxima are attained when $pt = 0, \pi$, etc.; positive maxima when $pt = (\pi/2), (3\pi/2)$, etc. (See Figures 9 and 10.) For the case under consideration (11) may be written

$$e = E \sin^2 pt - E \cos^2 pt. \qquad (14)$$

Thus the positive maxima, at $pt = (\pi/2)$, $(3\pi/2)$, etc., are due entirely to the *motion* of the magnetic system; and the intermediate negative, and equal, maxima at 0, π, etc., entirely to the *rate of change* of its moment. At B and F, and likewise at D and H, the two terms are equal and opposite and e vanishes. Between B and D, and likewise between F and H, the first or motional, term is preponderant; between H and B, and likewise between D and F, the second, or variational, term is preponderant. Thus with the conventions adopted here, the positive loops are chiefly motional, the negative are chiefly variational.*

The experimental magnetic systems

The magnetic systems used in nearly all the experiments described here are illustrated in Figure 2. A square bakelite block five cm on the side and 1.5 cm thick is mounted symmetrically, as the Figure shows, on a rod exactly similar to that which carries the rotating ring, so that the two rotating systems are interchangeable. Each of the larger sides of the block is milled with nine equally spaced grooves normal to the rod. For use in most of the work annealed rods of permalloy five cm long and 0.5 mm in diameter were cemented into four of these grooves at equal distances apart on each side. For use in a part of the work ten additional similar rods were cemented into the remaining ten grooves. And in a small part of the work two steel rods 5.3 cm long and 3.4 mm in diameter were substituted for the permalloy system.

Experiments with the 8-rod system

Very weak fields—In applied magnetic fields up to four gausses in strength pure sine-waves with the frequency $2f$ are obtained, and the proportionality between E and G, M (or V) and f is verified.

In any of the weak fields in which equation (13) is valid, and at $f = 60$ rps, the emf given by the rotating magnetic system is about 3.8 times as great as that given by the thick ring.

Figure 12 gives an oscillogram with two sine-waves, that given by the eight-rod system in a field of strength 3.7 gausses at 60 rps, and that given by the 60-cycle-per-second mains which drove the synchronous motor, 4.0 volts rms being applied to the oscillograph terminals.

Weak fields—In Figure 11 is exhibited the relation between the complete range of emf from crest to trough on the oscillograph screen and the intensity of the applied field for strengths up to 6.25 gausses. The frequency of rotation is 60 rps.

Stronger fields—Departure from sine-wave form begins when the field-strength is not much in excess of four gausses, and becomes more and more pronounced with further increase. A series of oscillograms made at 60 rps

*The effects produced in the case of the rotating ring can of course be analyzed in this same manner.

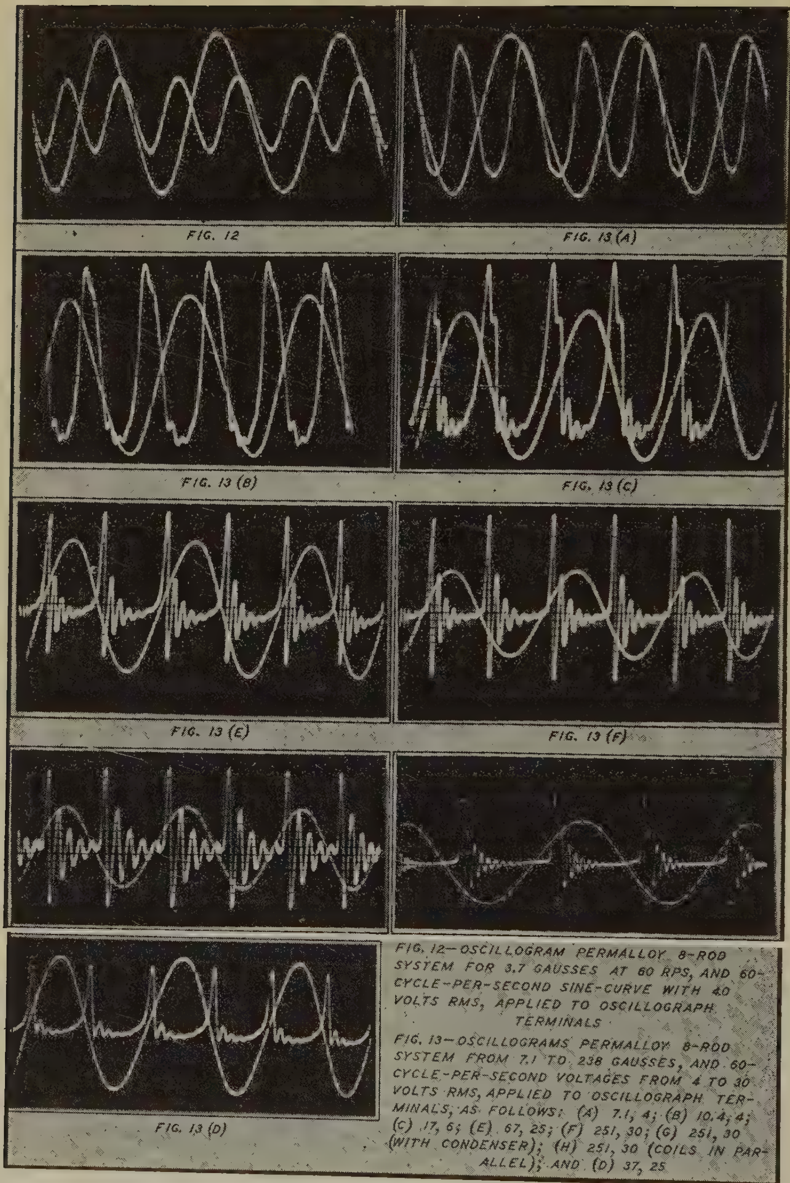


FIG. 12—OSCILLOGRAM PERMALLOY 8-ROD SYSTEM FOR 3.7 GAUSSES AT 60 RPS, AND 60-CYCLE-PER-SECOND SINE-CURVE WITH 40 VOLTS RMS, APPLIED TO OSCILLOGRAPH TERMINALS

FIG. 13—OSCILLOGRAMS PERMALLOY 8-ROD SYSTEM FROM 7.1 TO 238 GAUSSES, AND 60-CYCLE-PER-SECOND VOLTAGES FROM 4 TO 30 VOLTS RMS, APPLIED TO OSCILLOGRAPH TERMINALS, AS FOLLOWS: (A) 7.1, 4; (B) 10.4, 4; (C) 17, 6; (E) 67, 25; (F) 251, 30; (G) 251, 30 (WITH CONDENSER); (H) 251, 30 (COILS IN PARALLEL); AND (D) 37, 25

and in fields ranging in strength from 7.1 gausses up to about 238 gausses is given in Figure 13(*A*) to (*H*). Each of these curves is accompanied by another on the same film produced by applying a 60-cycle-per-second voltage of the magnitude indicated to the oscillograph terminals. [It is to be noted that the indications for Fig. 13(*G*) and Fig. 13(*H*) were inadvertently deleted when revising block to add Fig. 13(*C*).]

As the field-strength increases, and as would be expected from the shape

of the magnetization curve, the points B and D (Figure 10), and likewise F and H, move farther apart, the positive loops occupy a greater proportion of the period than the negative loops, which are therefore higher, since $\int e\mathrm{d}t$ for the whole cycle is zero. The advent of hysteresis is made evident by the asymmetry of the negative loops, but becomes masked when saturation approaches. When saturation is near for almost the whole period, m in (12) is nearly constant for all but the extreme parts of the positive loops, which are then again nearly sine curves [or rather, would be if it were not for the high-frequency oscillations (see below)]. The quantity $(\mathrm{d}m/\mathrm{d}t)$ on the other hand nearly vanishes except when $\cos pt$ is close to unity, when it becomes very large since the magnetic moment changes in a very small part of the period between its maximum positive value and its maximum negative value.

Figure 14, upper curve, shows the way in which the height of the negative peak changes with field-strength at 60 rps. One ammeter-division for this curve = 3.1 gausses.

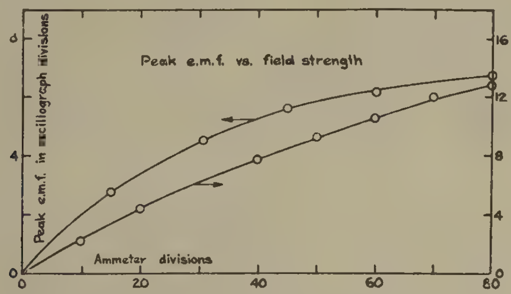


FIG. 14

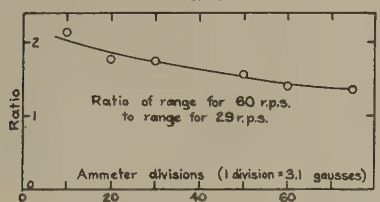


FIG. 15

FIG. 14—HEIGHT OF NEGATIVE PEAK VERSUS FIELD-STRENGTH AT 60 RPS
[ONE AMMETER-DIVISION = 3.1 GAUSSES FOR UPPER CURVE (8-MAGNET SYSTEM), AND = 3.35 GAUSSES FOR LOWER CURVE (18-MAGNET SYSTEM); EMF-SCALE AT LEFT APPLIES TO UPPER CURVE AND THAT AT RIGHT, TO LOWER]

FIG. 15—RATIO OF RANGE FROM CREST OF POSITIVE APPROXIMATE SINE-CURVE TO CREST OF NEGATIVE CURVE AT 60 RPS TO CORRESPONDING QUANTITY AT 29 RPS VERSUS FIELD-STRENGTH

For Figure 15 the range on the oscillograph screen from the crest of the positive approximate sine-curve to the peak of the negative curve was obtained as a function of the field-strength at 60 rps, and also at 29 rps. The ratio of the first to the second is plotted in the Figure as a function of the field-strength.

The oscillations apparent in the curves are of course due to the presence of inductance and capacity in the circuit. Figure 13(G) shows the increase of period due to connecting a condenser of 0.001-mf capacity to the oscillograph amplifier-terminals. Some decrease in oscillation-period occurs when connections are made directly to the plates of the oscilloscope tube. When the connections of the Helmholtz coils are changed from series to parallel arrangement the inductance is divided by four, and the frequency of the oscillation is doubled, as shown in the curve of Figure 13(H).

Experiments with the 18-rod system

When the 18-rod system replaces the eight-rod system, so that the number of rods is increased in the ratio 2.25 to 1, the demagnetizing factor is increased to such an extent that pure sine-waves are produced up to at least eight gausses. In these weak fields the sensitivity is about 1.37 that with the eight-rod system.

At 10.4 gausses the curves are still very nearly of sine-form, and no oscillations are manifest; at 17 gausses oscillations begin to appear on the lower loop; at 37 gausses the curve resembles that of Figure 13(C) (17 gausses) rather than that of Figure 13(D) (37 gausses), obtained with the eight-rod system; at 67 gausses and 252 gausses the curves resemble those obtained in similar fields with the eight-rod system, but the emfs are of course greater.

As saturation approaches, and as would be expected, the ratio of the 18-rod emf to the eight-rod emf increases from its value 1.37 in very weak fields toward the ratio 2.25. Thus at 67 gausses it is 1.55 and at 252 gausses it is 2.05.

Figure 14, lower curve, shows the way in which the height of the negative peak changes with field-strength at 60 rps. One ammeter-division for this curve is 3.35 gausses.

After these experiments were made the high-sensitivity Helmholtz coils were replaced by the low-sensitivity coils. As these coils had the same shape, size and locations as the others, the constant G was less in the ratio of the number of turns, namely, $165/11{,}000 = 0.015$.

Oscillograms of the emf in fields of strengths 33.9 and 268 gausses are given in Figure 16. In each case the base-line also was photographed, as well as a 60-cycle-per-second sine-wave with the rms-voltage indicated. The inductance of the low-resistance coils is only $(0.015)^2$ times that of the others, so that, as would be expected, no high-frequency oscillations are apparent.

Intensity-meter or variometer

In very weak fields the rotating-rod instrument is likely to be useful as a magnetic intensity-meter, or as a variometer, like the equipment with the rotating coil or ring.

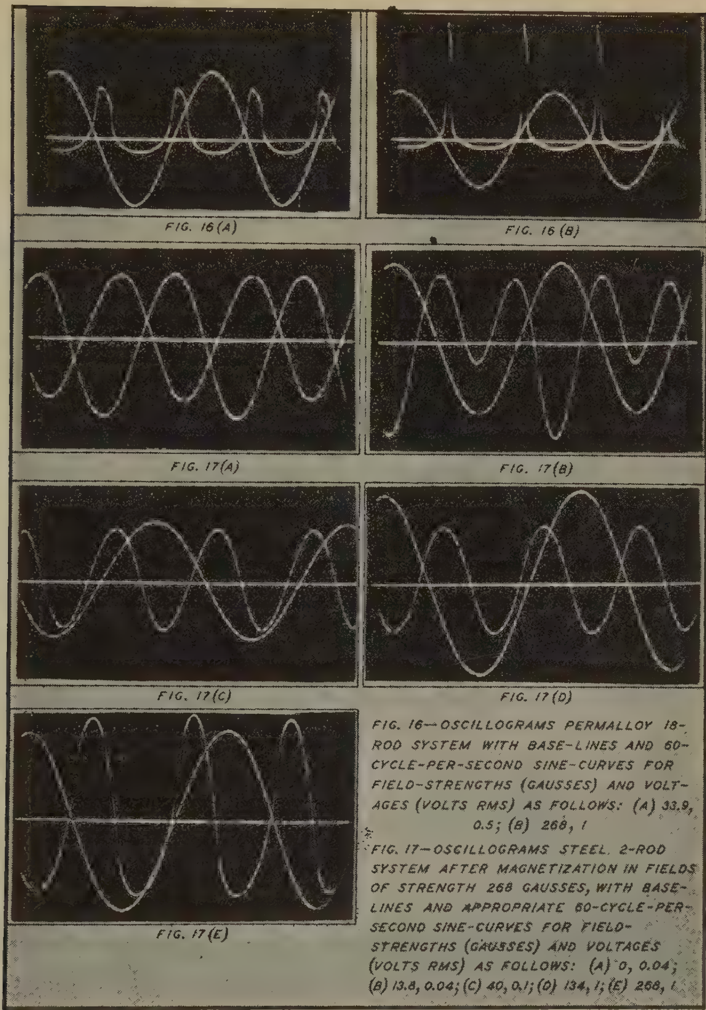


FIG. 16—OSCILLOGRAMS PERMALLOY 18-ROD SYSTEM WITH BASE-LINES AND 60-CYCLE-PER-SECOND SINE-CURVES FOR FIELD-STRENGTHS (GAUSSES) AND VOLTAGES (VOLTS RMS) AS FOLLOWS: (A) 33.9, 0.5; (B) 268, 1

FIG. 17—OSCILLOGRAMS STEEL 2-ROD SYSTEM AFTER MAGNETIZATION IN FIELDS OF STRENGTH 268 GAUSSES, WITH BASE-LINES AND APPROPRIATE 60-CYCLE-PER-SECOND SINE-CURVES FOR FIELD-STRENGTHS (GAUSSES) AND VOLTAGES (VOLTS RMS) AS FOLLOWS: (A) 0, 0.04; (B) 13.8, 0.04; (C) 40, 0.1; (D) 134, 1; (E) 268, 1

Impulse and harmonic generator

Through operation with strong fields the instrument may have useful applications as an impulse-generator, and as a generator of numerous harmonics.

The system of two steel rods: Operation when residual magnetism is present

If the field vanishes and the moment of the rotating magnetic system is permanent, the second term of (11) disappears and we have, as the first term shows, a sine-wave generator with the frequency of the rotation. The

instrument then becomes essentially identical with one described in 1864 by W. Weber.

If the field is present, and the moment of the magnet has a permanent component, an emf of the rotation-frequency will be superposed upon that of twice the frequency, but can readily be filtered from the output.

Oscillograms for the two-rod system driven at 60 rps after magnetization in a field of strength 268 gausses are given in Figure 17* for fields with intensities 0, 13.8, 34, 134, and 268 gausses. They are accompanied by zero emf base-lines and appropriate 60-cycle-per-second curves as indicated. The effects of residual magnetism and hysteresis are quite apparent. In the strongest fields saturation is still remote. In the first oscillogram, that for a neutral field, the curve with the smaller amplitude is that due to the rotating rods. The 60-cycle-per-second comparison curve is vertically displaced by accident. The two are equally good sine-curves.

Nearly all of the experimental work has been done in the Norman Bridge Laboratory, with facilities provided by the University, the Institute, and the Carnegie Institution of Washington. The preliminary tests referred to in the introduction were made two years ago at the Point Firmin Naval Station by the late Lieutenant Commander R. D. Lemert, Officer-in-Charge of Submarine Detection, and G. Gunkel, the work having been undertaken at the urgent solicitation of the United States Navy. For help with the oscillograms and diagrams, I am indebted to Louis Reeder of the Institute's Photo Service and to Dr. W. O. Wagner.

THE UNIVERSITY OF CALIFORNIA AND
THE CALIFORNIA INSTITUTE OF TECHNOLOGY,
Pasadena, California, February 19, 1946

*In title of Figure 17 last line should read "(*C*) 34, 0.1" instead of "(*C*) 40, 0.1."

THE SOLID ANGLE OF THE CORPUSCULAR SOLAR RADIATION

By M. N. Gnevishev and A. I. Ol

Summary—In this paper an attempt is made to determine the value of the solid angle of the Sun's corpuscular streams. This value has great importance in investigations of the influence of the solar activity on the nature of the active processes on the Sun. The solid angle of the corpuscular solar radiation may be evaluated by using data on: (1) The duration of the magnetic storms; (2) the increase of geomagnetic activity during the equinoctial seasons; (3) the correlation-coefficients between magnetic activity and area of sunspots in the central zones with different radii; (4) the lag of the 11-year variations of geomagnetic activity in comparison with the solar index owing to Spörer's law.

The researches show that the solid angle of the solar corpuscular streams is from 8° to 9°.

There are some indubitable symptoms that the increase of solar activity (the appearance of sunspots, faculae, chromospheric phenomena, and so on) is accompanied with an intensive growth of the ultra-violet radiation and the emission of corpuscular streams. The reality of the increase of the ultra-violet radiation in the Sun's active regions is corroborated by the well-known Dellinger's effect [see 1, 2, 3 of "References" at end of paper]. As it was shown by numerous investigations this phenomenon is due to the intensification of the ultra-violet solar radiation.

The existence of corpuscular streams emitted from the Sun's active regions is proved by the analysis of geomagnetic disturbance. It is quite certain that the magnetic storms are caused by the active processes on the Sun. In addition the following principal features of the magnetic storms also have been established:

(*a*) The intensity of geomagnetic storms increases with the approach to the polar regions. Its maximum is attained on the auroral zones, that is, near the geomagnetic parallels of $\pm 67°$. Thus it is evident that distribution on the Earth's surface of the agent responsible for the geomagnetic disturbance is thoroughly determined by the geomagnetic field.

(*b*) The geomagnetic disturbances are most intense on the night side of the Earth. The two features (*a*) and (*b*) of geomagnetic storms are in good agreement with theoretical calculations made by Störmer and the experiments by Birkeland and Brücke, in which the authors have studied the movement of charged particles in the field of magnetized sphere.

Chapman and Ferraro, on the one hand, and Hulburt and Maris, on the other, have discussed this problem. Chapman and Ferraro supported the hypothesis described above. Hulburt and Maris assumed that the geomagnetic disturbance is connected with charged particles of terrestrial origin; from their point of view these particles are formed by the ionization

of the upper layers of the Earth's atmosphere owing to the influence of the solar ultra-violet radiation. It is now possible to consider the Hulburt-Maris hypothesis to be erroneous because (1) such a physical mechanism is unreal and (2) the solid angle of solar radiation responsible for the geomagnetic storms is small.

The value of the solid angle of solar corpuscular streams can be estimated on the following grounds: (1) As it was shown by Chapman and Ferraro [4] the time of the Earth's presence in the corpuscular streams may be found from the duration of the magnetic storm. In fact, adopting the duration of the magnetic storm to be about two days, and taking into account the mean velocity of the Sun's rotation (13°.2 per day) we obtain the approximate value of the solid angle as 26°.

It is obvious, however, that this estimate gives only the upper limit of the solid angle since the duration of magnetic storms depends also on the dimensions of the emitting region of the solar surface. This manner of estimation shows the solid angle of the solar corpuscular radiation to be less than 26° in every case.

It should be noted that the short duration of the active stage of the magnetic storm cannot be attributed to the short time of corpuscular emission in the solar active region. The 27-day recurrence-tendency of geomagnetic storms shows this time to be about several months. The duration of the active stage of the magnetic storms, therefore, is determinated by the time the Earth is in the corpuscular stream rather than the time of the stream's existence.

(2) It was found by M. N. Gnevishev [5] that the correlation-coefficients between the mean half-year values of sunspot-area in the central zone with radius 30° and the mean half-year values of the daily amplitudes of the horizontal component of the geomagnetic field in Pawlowsk (near Leningrad) is $+ 0.79 \pm 0.10$. The same value of the correlation-coefficient ($+ 0.78 \pm 0.10$) was found between the same values of the horizontal component and the sunspot-areas in the central zone with radius 6°. The areas of sunspots in the annular zone with outer radius 30° and inner radius 6° give the correlation-coefficient as $+ 0.19 \pm 0.24$.

The obvious explanation of these results is that the sunspots disposed far enough from the center of the visible Sun's disk have no physical connection with the geomagnetic storms.

It follows from the above comparison of the correlation-coefficients that the value of the solid angle of the solar corpuscular radiation is less than 12° (that is, is equal to the double angular radius of the central zone through the center of which passes the line connecting the centers of the Sun and the Earth).

The corroboration of these considerations may be seen in Table 1. The second column of Table 1 shows for 1916 to 1940 the sums of the areas

of all the sunspot-groups observed during each year in heliographic latitudes less than 16°. The third column gives the annual sums of sunspot-areas in latitudes greater than 16°. The last column shows the sums of storm-amplitudes for all storms during the year (according to Pawlowsk Catalogue of geomagnetic storms). The sunspot-areas are given in units of 0.0001 of the Sun's hemisphere; the sums of amplitudes of the geomagnetic storm are given in units of 10γ.

TABLE 1

Years	Sum of spot-areas in latitude		Sums amplitudes magnetic storms
	Less than 16°	Greater than 16°	
1916	132	138	520
1917	266	238	724
1918	259	131	735
1919	288	66	736
1920	171	27	582
1921	141	7	344
1922	90	1	127
1923	11	9	159
1924	9	85	155
1925	47	246	267
1926	123	295	767
1927	218	447	500
1928	326	138	539
1929	342	73	683
1930	149	33	778
1931	98	6	234
1932	56	0	309
1933	32	0	197
1934	8	35	168
1935	27	204	240
1936	129	322	284
1937	346	310	942
1938	390	271	1477
1939	380	143	1502
1940	319	52	1033

The correlation-coefficient between the second and the fourth columns of Table 1 is $+ 0.86 \pm 0.05$ and that between the third and the fourth columns is $+ 0.35 \pm 0.18$.

Thus, in fact, for the influence on the geomagnetic field only the spots located not far from the direction to the Earth are of importance. If the sunspots with latitudes greater than 16° are taken into account the correlation-coefficients are decreased. Indeed the correlation-coefficient be-

tween the fourth column and the column obtained by summing the second and the third columns is $+ 0.76 \pm 0.08$.

(3) If the solid angle of the solar corpuscular radiation is small enough, the degree of influence of the corpuscular radiation on the geomagnetic field should vary during the year owing to the change of the Earth's heliographic latitude. Thus, in spring and in autumn, when the Earth is projected on the latitudes nearest to the zones of the maximum solar activity, the most intense geomagnetic activity must be observed.

As is known, this phenomenon is a real one and is called the "Cortie effect." Since the changes of the Earth's heliographic latitude are small ($\pm 7°$ to $\pm 23°$) it is obvious that this effect is possible only when the solid angle of the solar corpuscular streams is of the same order.

If such an explanation of the Cortie effect is true, these equinoctial maxima of the geomagnetic disturbance must be especially pronounced in those years when, according to Spörer's law, the solar activity is concentrated in the lowest latitudes. To check this supposition all the years from 1878 to 1940 were divided into three groups according to the mean heliographic latitude of sunspots. To the first group were assigned the years with the mean annual heliographic latitude of sunspots (φ) less than 12°, to the second group those for φ between 12° and 19°, and to the third those for φ greater than 19°. For each group the seasonal variation of the number of geomagnetic storms (according to the Pawlowsk Catalogue) was found. Then every seasonal variation was compared with the yearly variation of the Earth's heliographic latitude (the sign not being taken into account). Table 2 gives the resulting correlation-coefficients.

TABLE 2

Group of year	Correlation-coefficient	Error of correlation-coefficient
I, $\varphi \leq 12°$	$+ 0.68$	± 0.15
II, $12° < \varphi < 19°$	$+ 0.33$	± 0.26
III, $\varphi \geq 19°$	$+ 0.20$	± 0.28

In order to estimate the reality of the results obtained the same correlation-coefficients were computed for occasional selection from the first and the second groups. These selections were made in such a manner as to bring the populations in all the groups to a uniform level. The correlation-coefficients found were $+ 0.68$ for the first group and 0.20 for the second. These values confirm the reality of the data of Table 2. Therefore the spring-autumn maxima of the geomagnetic activity are very pronounced

in those years when the mean heliographic latitude of sunspots is less than 12°.

This result has entirely corroborated Cortie's basic idea, that the spring-autumn maxima of the geomagnetic activity are connected with the approach of the Earth's projection on the Sun's disk to the zones of the maximum solar activity. It should be noted that several investigator's, including J. Bartels [6], assumed the seasonal variation of the geomagnetic variation to be due to the change of the angle between the geomagnetic axis and the line connecting the centers of the Sun and the Earth. The present investigation shows a complete failure of this point of view.

Assuming the above-mentioned Cortie's explanation to be trustworthy, one comes to the conclusion that the solid angle of the corpuscular solar radiation is less than 14° because in the opposite case the seasonal variations (within $\pm$ 7°) of the angular distance of Earth's projection from the zones of maximum solar activity would not lead to sharply marked distinctions of the geomagnetic activity during different seasons.

(4) It is known that, according to Spörer's law, during the 11-year solar cycle the mean heliographic latitude of sunspot decreases from 25° to 30° in the beginning of the cycle to 6° to 7° in the end. At the time of the maximum solar activity the mean latitude of sunspots is about 15°, that is, sunspots are, on the average, far enough from the direction to the Earth. The optimal conditions for the rise of geomagnetic disturbances occur at the time when the solar activity is concentrated on the latitudes located nearer to the Earth's projection on the Sun's disk.

This must lead to the lag of the 11-year curve of geomagnetic activity as compared to the appropriate sunspot-curve. There are some indications by Chapman [7] and others, that there is such a phenomenon in fact. In order to obtain a more definite solution of this question we undertook special investigation and found that since 1879 there is such a lag in all the 11-year cycles. In this investigation, for every cycle of geomagnetic activity (which was indicated by the number of storms in a year) from 1878 till 1943, the relation of the number of storms in the second half of the cycle to that in the first half was determined. Let us denote this relation by A. In the same manner the relation, designated B, of sums of Wolf numbers in the second half of the cycle to those in the first half were computed. Table 3 gives the values of A and B for every 11-year cycle from 1879 to 1943.

The division of every 11-year cycle into the first and the second halves was made in the following manner. The years of beginning and of ending of every cycle were determined according to the minimum number of geomagnetic storms (the years of minimum being determined in such a way either to coincide or to differ by $\pm$ 1 year from those of Wolf numbers). Then the interval between the two consecutive minima was divided into

halves. When dealing with these data no account was taken whether the middle of the cycle (obtained in this manner) coincided or not with the maximum of solar or geomagnetic activity.

TABLE 3

Cycle	A	B	(A/B)
1879–1889	1.01	0.46	2.20
1890–1901	0.60	0.36	1.67
1902–1912	1.99	0.81	2.46
1913–1922	1.73	1.05	1.65
1923–1933	1.03	0.62	1.66
1934–1943	0.98	0.62	1.58
Mean value of (A/B)			1.87

It is to be noted that the years of beginning and of ending of the solar and the geomagnetic cycles were taken to be the same. Table 3 shows that, despite considerable variation in the value of (A/B) from cycle to cycle, the relation always exceeded unity and was 1.87 on the average. Hence it is clear that the majority of geomagnetic storms occurs during the second half of a solar cycle. Therefore the solar phenomena are more effective with regard to the geomagnetic field during the last part of the 11-year cycles, that is, for the time when, according to Spörer's law, the latitudes of the greatest solar activity are nearest the direction to the Earth. This proves the smallness of the solid angle of solar corpuscular radiation and makes possible an estimate of that angle.

Let M be the number of geomagnetic storms (or any other index of geomagnetic activity), S be the Wolf number (or any other index of the solar activity), and φ be the mean annual heliographic latitude of sunspots. Supposing that the influence of solar activity on the geomagnetic field is as great as S, and depends on the angle between the normal to the solar surface in the center of the active region and the direction to the Earth, we write

$$M = S \times F(\varphi - \beta)$$

where $\beta = 4°.6$ is the mean annual heliographic latitude of the Earth (computed without taking the sign into account). The function $F(\varphi - \beta)$ expresses the dependence of the intensity of the corpuscular stream on the angle between the normal to the emitting surface and the direction to the Earth. This function may be readily determined from

$$F(\varphi - \beta) = (M/S)$$

Plotting the relation (M/S) as ordinate against $(\varphi - \beta)$ as abscissa for the same year, we obtain the form of function $F(\varphi - \beta)$. The function obtained in such a manner using 66 points (1879–1944) is shown in Figure 1.

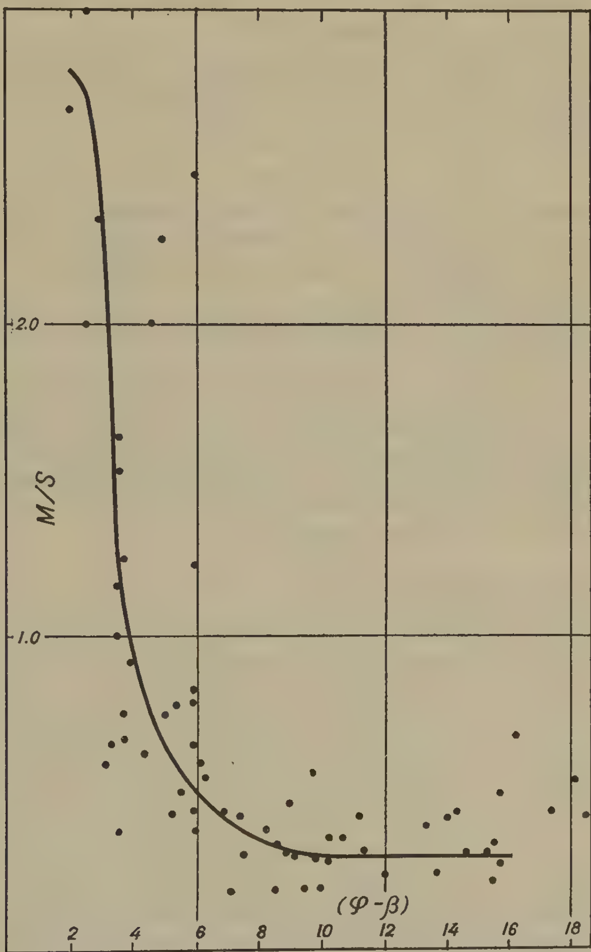


FIG. 1—GRAPH OF (φ-β) AGAINST (M/S), 66 POINTS, 1879-1944

One can clearly see a very sharp drop of the curve in the neighborhood of $(\varphi - \beta) = 4°$. Hence we conclude that the approximate value of the solid angle of corpuscular radiation is about 8° to 9°.

Summarizing the above considerations the following conclusions are to be made:

(1) The short duration of the active stage of the geomagnetic storms suggests the smallness of the solid angle of the solar corpuscular stream.

(2) The persistence of the spring-autumn maxima of geomagnetic

activity confirms (1); it is found that the explanation of this effect given by Cortie is preferable to that by Bartels.

(3) From the correlation-coefficients between geomagnetic activity and sunspots in the central zones of different radii one may conclude that the solid angle in question is less than 12°.

(4) From comparison of the 11-year curves of the solar and geomagnetic activities the value of the solid angle of the corpuscular streams is found to be about 8°.

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Poulkovo Observatory,
Leningrad, U.S.S.R., December 1, 1945

ATMOSPHERIC-ELECTRIC POTENTIAL-GRADIENT IN KOKKOLA, FINLAND, DURING THE SOLAR ECLIPSE OF JULY 9, 1945

By E. Sucksdorff

In addition to other geophysical and geodetical investigations made in Finland in connection with the total solar eclipse in the summer of 1945, a set of measurements was also made of the atmospheric-electric potential-gradient. The latter was to determine the influence of the eclipse on changes in the potential-gradient for comparison with the variations on the following days. The observations were made in the neighborhood of the small town of Kokkola in the north of Finland (latitude = 63° 51′ north, longitude = 23° 10′ east). A small field about two km northeast of the town was selected as place of observation. Its situation is 2.5 km from the Gulf of Bothnia at an elevation above sea-level of only a few meters, and 11 km southwest from the central line of the eclipse.

Here the first contact of the eclipse was established on July 9, 1945, at $14^h\ 54^m.5$ and the last contact at $17^h\ 08^m.8$ East European time (EET = GMT + 2^h). The totality lasted from $16^h\ 02^m.9$ to $16^h\ 04^m.0$ EET.

Instruments

A bifilar electrometer of Wulf-type No. 6190, manufactured by Günther and Tegetmeyer of Braunschweig, and an ionium-collector were used for the determination of the potential-gradient. The collector was attached to the top of a mast, the upper half of which consisted of an ebonite rod, at the height two meters above the ground. The collector was connected with the electrometer by a thin steel wire about six meters in length.

Readings of the electrometer were made every minute, in sets of some ten minutes (see Table 1). No corrections were made to transform the tabulated readings to an undisturbed level.

A mechanically recording Benndorf quadrant-electrometer was also installed at Kokkola; unfortunately, however, the results obtained by it are inaccurate—apparently due to the temporary and very unsuitable site of the apparatus—to such an extent that they cannot be used.

Meteorological conditions

In the early morning hours of the day of the eclipse an inactive cold front had passed Kokkola. On account of this, cool and dry continental polar air streamed westward over the station. Consequently the sky cleared up in the morning and even the last clouds disappeared between 09^h and 10^h local time. The air was particularly transparent and, already before noon, the lower and cooler stratum of air had been warmed by solar

radiation. Thus the air-mass above Kokkola was, according to radio soundings, very homogeneous at the time of the observations. The sky remained absolutely cloudless until the following morning. During the period of observation the nearest clouds were at least 100 km from Kokkola. The wind blew from the direction of the mainland, until 13^h from the southeast, the velocity being four meters/sec, changed gradually to east-southeast (about 14^h) and east (about 15^h) remaining in that quarter until the end of the observations with velocity from four to six meters/sec.

During the eclipse the air-temperature decreased by 4°.8 C, from a maximum 28°.1 at $15^h\,00^m$ to a minimum of 23°.3 at $16^h\,10^m$ (psychrometric measurements, made some three km away, showed a decrease of 3°.0 only). According to observations carried out by Professor Keränen at the same place the intensity of the total solar radiation was 1.2 gcal/cm^2 immediately before the eclipse and 1.1 gcal/cm^2 immediately after it.

The meteorological conditions (and also the time of the day) were thus extremely favorable for atmospheric-electric measurements, as disturbing atmospheric factors were almost non-existent. Accordingly the single electrometer-readings showed only little scatter from the means.

It may be mentioned further that there are in the vicinity—or even far away on the windward side—no industrial plants or other institutions which might have polluted the air by smoke, for instance, thus increasing artificially the concentration of nuclei.

Results of observations

The results of atmospheric-electric potential-gradient measurements on the day of the eclipse and on the following day are shown in Table 1. They are also graphically represented in Figure 1, in which the continuous curve

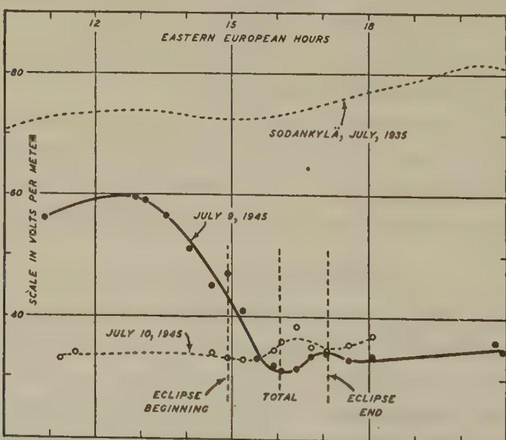

FIG. 1—CHANGE OF POTENTIAL-GRADIENT, KOKKOLA: ON SOLAR ECLIPSE DAY (CONTINUOUS CURVE), ON DAY AFTER ECLIPSE (LOWER DOTTED CURVE); AND FAIR-WEATHER CURVE FROM SODANKYLÄ FOR JULY, 1935

shows the variations on the day of eclipse, the lower dotted curve the variations on July 10, and the upper dotted curve, for comparison, the average changes in the potential-gradient at Sodankylä during ten fair-weather days in July, 1935.

It may be seen from Figure 1 that the potential-gradient at first followed its normal daily course. About two hours before the beginning of the eclipse, the potential-gradient began, however, to decrease suddenly and this fall continued steadily until a minimum was reached at the time of totality, the potential-gradient amounting then only to half of the initial value. Then a slow increase began, although the values of the potential-gradient remained exceptionally low until late at night. In other words, the solar eclipse caused a marked and smooth diminution of the potential-gradient which began two hours prior to the beginning of the optical eclipse and continued even after the end of the visual eclipse. (In the author's opinion any kind of defects of insulation may be ruled out altogether.)

On July 10 the meteorological conditions were nearly as favorable as on the day of the eclipse, even though scattered light fair-weather cumulus clouds were visible on the sky. The wind varied between southeast and east-southeast and its average velocity was four meters/sec. Thus the change of the potential-gradient was smooth also on this day, being, however, comparatively low.

TABLE 1—*Observations of the atmospheric-electric potential-gradient on day of solar eclipse, July 9, 1945, and the following day, Kokkola, Finland*

Time EET July 9, 1945	Potential-gradient	Time EET July 10, 1945	Potential-gradient
h m h m	*V/m*	*h m h m*	*V/m*
10 49–11 00	56	11 10–11 20	33
12 50–13 00	59.5	11 30–11 40	34
13 01–13 10	59	14 30–14 40	34
13 30–13 40	56.5	14 50–15 00	33
14 00–14 10	51	15 10–15 20	33
14 30–14 40	45	15 30–15 40	33
14 50–15 00	47	15 50–16 00	34.5
15 10–15 20	41	16 00–16 10	36
15 30–15 40	33	16 20–16 30	38.5
15 50–16 00	32	16 40–16 50	35
16 00–16 10	31	17 00–17 10	34.5
16 20–16 30	31.5	17 30–17 40	35.5
16 40–16 50	33.5	18 00–18 10	37
17 00–17 10	34		
17 30–17 40	33		
18 00–18 10	33.5		
20 43–20 50	36		
20 51–21 00	34.5		

On the following days the weather became thundery and the results obtained by the measurements on these days are outside the range on Figure 1.

Normal curves

Unfortunately no records of the potential-gradient in Kokkola are available. Figure 2 shows (so far unpublished) smoothed fair-weather

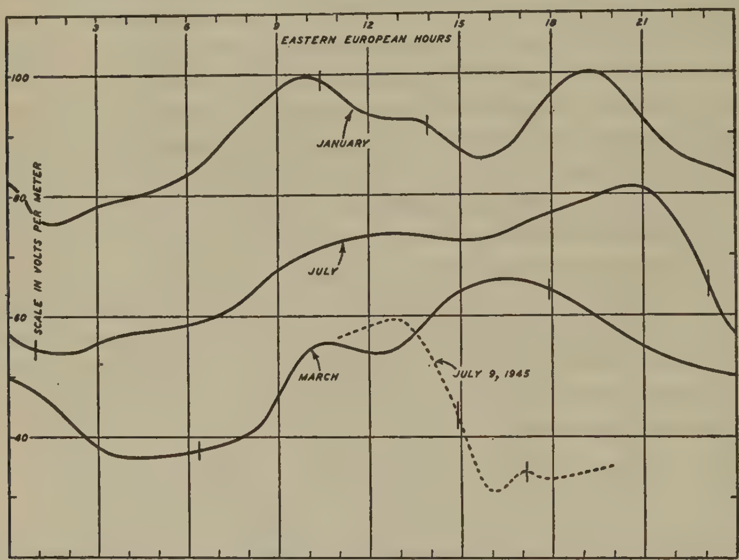

FIG. 2—SMOOTHED FAIR-WEATHER CURVES SHOWING DAILY VARIATION OF POTENTIAL-GRADIENT, SODANKYLÄ, JANUARY, JULY, AND MARCH, 1935 (DOTTED = CHANGE ON DAY OF SOLAR ECLIPSE IN KOKKOLA)

curves of the daily variation for single months during winter, equinox, and summer during 1935 from Sodankylä Observatory, situated about 3°.5 north of Kokkola (latitude = 67° 22′ north, longitude = 26° 39′ east). The atmospheric-electric conditions at Sodankylä, lying far away in the interior of the country with a typical inland climate, may perhaps differ in some measure from the conditions in Kokkola, on the coast of the Gulf of Bothnia; the effects of the sea were not felt during the period of observation, however, as there was a steady wind from the direction of the mainland. It would, therefore, seem possible to use these curves—in the absence of better ones—as representative of the daily fair-weather variation of the potential-gradient in the north of Finland in general.

As seen from Figure 2 the curves of the daily variation are more or less markedly double-waved. The chief minimum occurs in the early morning and the chief maximum in the afternoon or evening. In July and also—although not so markedly—in March, the potential-gradient begins to decrease resolutely about two hours before sunset and to rise again definitely

after sunrise (the average time of sunrise and sunset are marked in the curves by short transverse lines). On the other hand, the abrupt falls and rises in the curve for January appear to be in no way associated with the position of the Sun, either above or below the horizon. The potential-gradient may rise or decrease also due to other causes, excepting those brought about directly by the Sun.

Discussion

The change observed during the eclipse, also represented in Figure 2 by a dotted line, in essential features resembles the descending phase of the daily curve of variation for July about the time of sunset, and similarly—although less distinctly—the corresponding phase in the curve for March; this is either a chance resemblance or due to the cause being the same in both cases.

The fall in the daily curves at the time of sunset can be explained as being due to the air-convection currents ceasing at night and a shallow stratum of quiet and cool air developing near the surface where radioactive matter coming from the Earth becomes abundant, but the concentration of nuclei diminishes; this increases the air-conductivity and consequently decreases the potential-gradient measured low in the atmosphere [see 1 of "References" at end of paper]. On clear days at Sodankylä the wind usually calms towards the evening in summer as well as during the winter; this circumstance apparently has a similar effect. It is further to be noted that the sunset in Northern Finland occurs very slowly, as the Sun approaches the horizon at a low angle and consequently the radiation of the Sun, which causes the atmospheric convection currents, has practically ceased already a few hours before the actual sunset. Thus it seems probable that the decrease of the potential-gradient observed in the Sodankylä daily curves of variation in the evening and at night and the setting in of this decrease quite some time before sunset, may be explained by the atmospheric convection currents coming to a standstill after the effect of radiation of the Sun has ceased and, in addition, by the calming down of the wind during nights following clear days.

A meteorological interpretation of the change observed in the potential-gradient on the day of the eclipse presents certain difficulties. The sudden start of the decrease as early as two hours prior to the first contact of the eclipse is indeed surprising. A stable air-stratum could not possibly develop near the surface, because there was a steady wind of velocity four to six meters/sec. The Sun's position was high on the sky (after the last contact still 30° above the horizon) and, according to Professor Keränen's observations, the amount of its light-radiation had decreased, being less than half of the initial value during one hour and less than the third of it during 40 minutes only. This time appears too short for influencing conditions in

the lowest atmosphere under the Moon's shadow in any more effective manner. After the eclipse the potential-gradient remained low, although the total light-radiation of the Sun had decreased from the setting in of the eclipse to the end of it by nine per cent only. The writer cannot find any meteorological circumstances by which the observed atmospheric-electric effect could be explained, excepting the equalization of the air-masses during the forenoon of the day of the eclipse, a possible mixing, and a slight turn of the wind before the eclipse. It also appears hardly likely that the phenomena mentioned above could have caused such a considerable change in the potential-gradient as actually observed.

By investigating statistically the geomagnetic records from Sodankylä during a period of 21 years, the writer has recently ascertained [2] that a decrease of about 15 per cent occurs in geomagnetic activity when the Moon's position is between the Sun and the Earth during new moon. The cause of this effect is unknown at present, but it appears as if the Moon would in some way or other screen the Earth from the effect of the Sun which appears as geomagnetic activity on the Earth. A similar effect has been noted when Mercury or Venus in lower conjunction is between the Sun and the Earth. The correlation between atmospheric electricity on one hand, and geomagnetism or the Sun's activity on the other hand, however, is fairly vague according to present views. Nevertheless, the writer is of the opinion that the marked change of the atmospheric-electric potential-gradient observed in Kokkola during the solar eclipse of July 9, 1945, discloses an effect which cannot be explained meteorologically, but is associated with the principal cause of the Earth's atmospheric-electric field.

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Meteorological Office,
Helsinki, February 18, 1946

ANNUAL VARIATION AT HONOLULU

By Guy C. Omer, Jr.*

Abstract—The annual variation of the Earth's field at Honolulu was determined for the X-, Y-, and Z-components. This was a necessary preliminary for a forthcoming study of the local volcanic variations at Honolulu.

The data of the Honolulu Magnetic Observatory have been under study at the Hawaiian Volcano Observatory to determine whether there is a perturbation of the Earth's field at Honolulu which would correlate with the volcanic states of the three active Hawaiian volcanoes—Kilauea, Mauna Loa, and Hualalai. In order to make this comparison, all cyclic and secular variations must be removed from the data so that only a non-periodic residue remains. It was necessary, therefore, to determine statistically the annual variation at Honolulu so that it too could be eliminated from the data. The comparison of the magnetic field at Honolulu, when freed from the secular and annual variations, with the volcanic states of the Hawaiian volcanoes will be made in a forthcoming paper.

The raw material used in this study was the published monthly means for ten selected quiet days of the X-, Y-, and Z-components during 1902-38. Since the means were taken over full days, the solar diurnal variation is averaged out. As the ten selected quiet days will fall at random times during each month, the lunar variation is partially eliminated. When sufficient masses of data are averaged together the lunar variation will be completely removed. The variations that will remain in the raw data are, therefore: (1) the secular variation; (2) the annual variation; (3) disturbance-variations; and (4) local variations produced by volcanic changes.

While the use of monthly means for the ten selected quiet days will minimize variation (3) for periods of low magnetic activity, it will be conspicuously present during times of moderate and high magnetic activity because of the slow recovery to normal values. Variations under (4) will be of small amplitude at Honolulu and will have a random distribution in time.

To eliminate the secular variation, a running mean of the monthly values was computed. In computing the X-component, an eleven-month running mean was used, centered on the month under consideration, and including the five preceding and the five subsequent months. This component seems to be the most important for volcanic correlations [see 1 of "References" at end of paper]. In computing the Y- and Z-components the centered month was suppressed for computational ease, leaving a

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ten-month running mean. The secular values for the first five months of 1902 and the last five months of 1938 were determined by graphical extrapolation from the computed values. These values are, of course, subject to the usual errors of judgment.

Beginning with 1913 a change in the absolute values was adopted at Honolulu. It was necessary to compensate for this change in the computations. This was effected by calculating the running means in the vicinity of January, 1913, from values offset by the proper amount from the published values. The corrections of 29 gammas for the X-component, 5 gammas for the Y-component, and 68 gammas for the Z-component given in the Honolulu yearbook [2] worked well and the two segments of the residual curves met smoothly.

The residuals between the running means and the monthly means would contain the annual variation, which is cyclic with a year as the period, and the disturbance and volcanic variations, which have random occurrence. Hence, with sufficient data, averaging by months would produce the annual variation. For the purposes of the volcanic study, the material was divided into three nearly equal groups according to the sunspot-cycle. These groups, along with their average Zürich relative sunspot-numbers (R) and their average u-measures of magnetic activity [3], are given in Table 1.

TABLE 1—*Years of low, medium, and high sunspot-numbers, Groups I, II, and III, respectively, 1902-38*

I, low $R = 9.2$ and $u = 0.64$			II, medium $R = 41$ and $u = 0.89$			III, high $R = 75$ and $u = 1.08$		
1902	1911	1912	1903	1904	1909	1905	1906	1907
1913	1914	1922	1910	1915	1916	1908	1917	1918
1923	1924	1931	1920	1921	1925	1919	1926	1927
1932	1933	1934	1930	1935	1936	1928	1929	1937
							1938	

The annual variations of the X-, Y-, and Z-components for these three groups as well as for the complete epoch are shown in Figure 1. The sense of the signs is the same as that adopted at Honolulu. A positive increase in ΔX indicates an increase in the northward component. A positive increase in ΔY indicates an increase in the eastward component. A positive increase in ΔZ indicates an increase in the downward component. The statistical populations of each of these three groups is rather small and there is undoubtedly some fluctuation in the results. The population of the complete epoch, however, is large enough so that random fluctuations should be almost averaged out. A vector representation of the annual

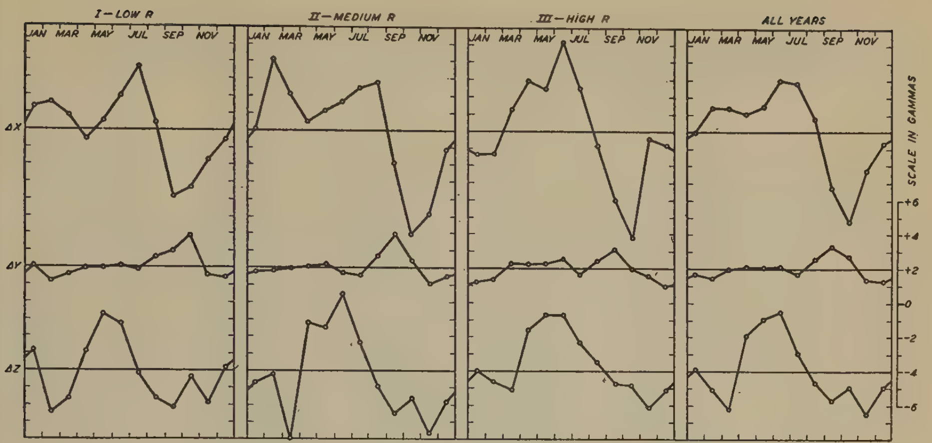

FIG. 1—ANNUAL VARIATION AT HONOLULU GROUPED ACCORDING TO THE SUNSPOT-CYCLE

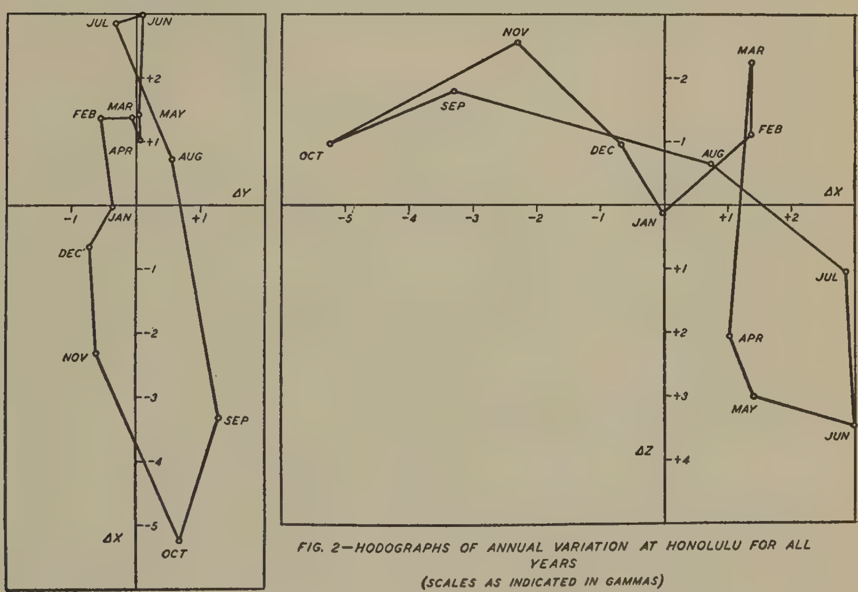

FIG. 2—HODOGRAPHS OF ANNUAL VARIATION AT HONOLULU FOR ALL YEARS
(SCALES AS INDICATED IN GAMMAS)

variation for the complete epoch is shown in Figure 2. The computed values of the annual variation for the complete epoch are given in Table 2. The annual variation, it will be observed, is small. Nevertheless, it is comparable to the volcanic variation, which is the ultimate effect being sought.

Table 2—*Annual variations for all years 1902-1938, Honolulu Magnetic Observatory*

Month	ΔX	ΔY	ΔZ
	γ	γ	γ
Jan.	−0.02	−0.37	+0.13
Feb.	+1.37	−0.57	−1.09
Mar.	+1.38	−0.06	−2.24
Apr.	+1.01	+0.06	+2.08
May	+1.40	+0.03	+3.02
June	+2.99	+0.09	+3.47
July	+2.86	−0.34	+1.05
Aug.	+0.72	+0.56	−0.66
Sep.	−3.31	+1.29	−1.79
Oct.	−5.25	+0.69	−0.95
Nov.	−2.31	−0.62	−2.57
Dec.	−0.69	−0.74	−0.95

The author wishes to thank the United States Coast and Geodetic Survey, both at Washington and Honolulu, for supplying the data upon which this study was founded.

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GEOMAGNETIC DATA ON VARIATIONS OF SOLAR RADIATION: PART I—WAVE-RADIATION

By Julius Bartels

Summary—From geomagnetic observations, the time-variations of two kinds of solar radiations can be deduced—a wave-radiation, W, and a particle-radiation, P. This paper, one of a series, derives and discusses homogeneous time-series for W and P; these data, in addition to their meaning for geomagnetism and solar physics, may serve as numerical basis for studies on other solar influences in geophysical or biological phenomena. Daily values δW_2 for the deviations of W from a normal value are inferred from suitably defined ranges of the solar diurnal-magnetic variation of the horizontal intensity at the Huancayo (Peru) Observatory of the Carnegie Institution of Washington, for March, 1922, to December, 1937. Averages for eighths and for three-eighths (= about ten days) of solar rotations are computed, also "smoothed decade-deviations" showing the quasi-persistent periodicities expressing the 27-day recurrence-tendency due to solar rotation. Monthly averages δW_1 are extended to include October, 1939. Comparable tables are derived for solar activity R (from Zürich relative sunspot-numbers R) and for particle-radiation P (from data for geomagnetic disturbance). *The correlations between* R *and* W *in "slow" variations (expressed in monthly, quarterly, and annual means) are the closest found so far between solar and terrestrial phenomena,* surpassing even those found between R and P.

The influence, on W and P, of changes in R in the course of solar rotations ("fast" variations) is studied by methods of correlation and by the superposed-epoch method. Systematic features affecting the results of both methods are demonstrated; the relative exaggeration of the main selected pulse is recognized, explained, and illustrated in a statistical model. Several statistical experiments agree that—except near sunspot-minimum—*the fast variations of* R *are accompanied by similar variations of* W, lagging by not more than about one day. Again, the statistical relation between R and P in the fast variations is found much weaker than that between R and W. Quantitatively, the relative effect of R on W in the fast variations is computed to be about 30 per cent smaller than in the slow variations, but reasons are given which interpret this result as compatible with the view that the relation between R and W in slow and fast variations does not differ essentially. The 27-day recurrence-tendency in W is just as strong as in R; there is an indication that the effect of a spot-group on W increases with its age, if equal sunspot-numbers are compared. The physical meaning of W is discussed; W is probably a solar radiation absorbed rather low in the ionosphere, in or near the same layer which is ionized by the excessive ultra-violet emitted by a solar eruption. A program for the systematic extraction of W from geomagnetic records is outlined.

Remark on symbols—Instead of using bold-face *sans serif* type, as the practice adopted in the book "Geomagnetism" [see 3 of "References" at end of paper], light *sans serif* type has been used to designate, in general, the three phenomena R = solar activity as seen on the Sun's surface, W = wave-radiation, and P = particle-radiation effective in geomagnetism. The letter S was already adopted for solar-diurnal magnetic variation, so R was chosen to represent Zürich *r*elative sunspot-numbers R. The letter C, which might have been suggested for corpuscular radiation, has been long used for daily international magnetic character-figures (here C_{int}), so that the letter P for the effect of solar *p*articles entering mainly in the zones of *p*olar aurora was preferred. The indices in the deviations δW_1 and δW_2 indicate conventionally that these quantities have been derived successively. § 13 collects data on scales.

§ 1. *Introduction; short characterization of* W *and* P

An earlier short paper [1] has outlined how the time-variations of two kinds of solar radiation—wave-radiation, W, and corpuscular (or particle-) radiation, P—may be measured by their geomagnetic effects. A first more extensive discussion has since appeared [2]; the manuscripts for the second and third parts were lost in the press at Berlin, but copies of results were saved, and are used here. The older work on this subject has been fully cited and discussed in "Geomagnetism" [3].

Neither W nor P reach the Earth's surface, both being absorbed high up in the atmosphere (ionosphere). A part of their energy is consumed in ionizing the air, so that electric currents can flow, mainly in horizontal circuits, which are caused presumably by dynamo-action. These currents are detected by their influence on the geomagnetic field; their strengths increase with the intensities of W and P.

It is proposed to derive homogeneous time-series for W and P, and to discuss their changes in the course of the 11-year sunspot-cycle, of the 27-day solar rotation, and from day to day. Beyond their meaning for geomagnetism and solar physics, these data may serve as numerical basis for the study of other solar influences in geophysical or biological phenomena.

W affects only the sunlit hemisphere. P is due to solar particles, some of which are charged electrically and therefore are deflected by the Earth's magnetic field, entering the ionosphere preferably in the zones of polar aurora, both on the day and night side. The action of W is most clearly expressed in the solar and lunar diurnal-magnetic variations on magnetically quiet days, S_q and L; P causes magnetic disturbance D.

Both W and P may consist of several parts of different physical nature; W might even comprise corpuscles, namely, neutral particles. Yet, in their geomagnetic effects, W and P are distinctly separable, and can be measured in two homogeneous scales. These scales are arbitrary, only chosen so that the numerical values are adequate; but although these scales bear, so to say, the eggshells of their geomagnetic origin, they have been found satisfactory, and it is a fortunate coincidence that the monthly means of W show an astonishingly linear relationship to such arbitrary a measure of solar activity as the Zürich relative sunspot-number R (§ 5).

The transformation of the scales necessary in order to express W and P in absolute units of energy would require a complete physical analysis, for which neither observation nor theory are fully available. Since "Geomagnetism" [3] was printed, some facts have been found which throw additional light on the physical meaning of the measures derived here; they will be discussed in § 22.

§ 2. *Restriction to geomagnetic data*

In recent years, much valuable information bearing on W and P has accrued by the use of new techniques in the astrophysical observations of

the Sun and in direct ionospheric research. From the statistical standpoint, geomagnetic data have the advantage of being available in unbroken series for several sunspot-cycles; the same holds for the sunspot-numbers R, or the closely correlated Greenwich spot-areas. While, therefore, the modern physical facts and theories furnish the background for the definitions of the numerical measures for W and P, the actual values given are extracted from geomagnetism alone; likewise, R-numbers are the only solar data used here for comparison. For similar reasons, the striking elementary phenomenon connected with solar eruptions—a violent rise in W coupled, in some cases, with an outburst of P reaching the Earth about 20 hours later—will not be discussed here separately; incidentally, geomagnetic records for a few cases have been communicated in the paper introducing the three-hour-range index as an international measure for P [4*a*].

§ 3. *The daily ranges used for measuring* W; *marking of less reliable values*

The expression for W used here is derived from the daily range (amplitude) A_S of the solar diurnal-magnetic variation S_q in the horizontal intensity H at the Huancayo Observatory. A_S is defined as the excess of the average of H from 09^h to 14^h (75° west meridian time) over the average from 00^h to 05^h, corrected for non-cyclic change and for the effect of the lunar-diurnal variation L; details are given in [2] and [5].

Among the various possible definitions for daily ranges, that for A_S has been so chosen as to suppress any influence of P; even a systematic lowering of A_S on disturbed days might have been expected through the daily-disturbance variation, S_D. This has been tested in [2] and [5]; at least for degrees of magnetic activity lower than that corresponding to an international character-figure $C_{int} = 1.2$, practically no influence of P on A_S exists, while even for more disturbed days (up to $C_{int} = 1.6$ or 1.7) A_S may be used as an approximate measure for W, unless there has been violent disturbance (world-wide range-indices 7, 8, or 9) between 00^h and 14^h. Because of the peculiar daily variation of the range-index at Huancayo [4*b*], disturbance in the night hours, 00^h to 05^h, affects A_S less than around noon.

Judging by three-hour-range indices, such days were picked out for which A_S is a less reliable measure for W, or for which W cannot be measured at all by A_S. Each day of the years 1922 to 1937 was thus ascribed to one of four groups: the great majority of "undisturbed" days, unmarked, with C_{int} under 1.2, for which A_S may be used without reservation; somewhat disturbed days, marked *p*, for which the value for W furnished by A_S, while doubtful for each individual *p*-day, may be used in averages for several days; highly disturbed days, marked *P*, for which S_q is so distorted that the effect of W is completely masked; finally, a few days for which A_S cannot be determined because the *H*-records were partly lost.

The numbers of days marked p and P vary, of course, from year to year, with the general change of magnetic activity in the 11-year cycle; for example, in the sunspot-minimum year 1933, there were five P-days and 19 p-days, while the sunspot-maximum year 1937 showed 17 P-days and 49 p-days.

§ 4. *Tables of monthly deviations for* R, W *and* P

The first step was to express the variations of the monthly means of R, W, and P by deviations δR, δW_1, δP from normals valid for medium solar activity, about $R = 50$; these deviations are all uniformly standardized as to have the same standard deviation $\sigma = 25$. For R, this definition leads, for the series of monthly means March 1922 to October 1939 considered, to the formula $\delta R = 0.649\ (R - 50)$.

The basis for δW_1 are the monthly averages of A_S computed from all undisturbed days (that is, with $C_{int} < 1.2$), given in Table 1.

TABLE 1—*Monthly means of daily amplitudes A_S of magnetic horizontal intensity H at Huancayo (Peru), for all days with international character-figure C_{int} under 1.2, March 1922 to October 1939*

(Unit $\gamma = 10^{-5}$ gauss)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1922	...	...	107	84	73	61	58	66	88	88	63	58
1923	75	80	93	101	66	55	68	77	92	98	61	52
1924	76	74	86	90	75	62	63	75	100	102	76	77
1925	90	72	95	101	78	75	74	78	125	127	100	106
1926	112	122	124	119	105	80	78	102	122	113	102	91
1927	112	128	148	135	98	84	80	94	126	141	94	95
1928	115	113	138	136	113	103	104	115	144	149	95	108
1929	114	131	134	125	94	78	89	95	118	122	101	115
1930	123	113	130	116	89	75	77	81	97	95	84	61
1931	83	83	98	96	69	52	76	75	89	94	65	61
1932	70	73	99	79	75	61	65	62	86	80	47	51
1933	70	88	82	74	66	51	53	71	87	85	57	61
1934	71	67	88	88	75	61	63	68	87	89	71	68
1935	78	87	83	87	80	63	75	88	100	103	92	99
1936	114	122	130	117	104	90	86	92	139	153	129	119
1937	153	166	159	132	117	110	108	137	149	154	133	119
1938	123	127	141	144	111	89	106	114	139	154	128	128
1939	131	131	120	132	115	103	107	127	142	152	...	...

From Table 1, the variations of W were expressed as average monthly deviations δW_1 from a normal value $A_{S;R=50}$, thus $\delta W_1 = \omega_1(A_S - A_{S;R=50})$. The two parameters ω_1 and $A_{S;R=50}$ are given in Table 2.

TABLE 2—*Parameters for computing monthly mean values of δW_1 from those of A_S*

Value	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
ω_1	1.04	0.90	0.82	1.13	1.43	1.36	1.79	1.30	1.02	0.88	0.94	1.00
$A_{S;R=50}$	102	103	120	111	89	75	79	91	115	118	90	86

The transition from A_S to δW_1 expressed by these formulas and parameters is chosen so that they give *standardized* values δW_1, namely:

(*a*) For each calendar month (for instance, for the 18 values for the month of March for the years 1922-39), the standard deviations of the monthly figures for δW_1 and for δR are equal, $\sigma(\delta W_1) = \sigma(\delta R)$.

(*b*) For all 212 monthly values δW_1, March 1922 to October 1939, taken together, the standard deviation $\sigma(\delta W_1) = 25$.

Finally, a similarly standardized series δP was computed, based, for want of better data, on the monthly means u_1 [3], $\delta P = fu_1 - g$, and defined so that for each calendar month, for example, for the 18 months of March considered, $\sigma(\delta P) = 25$, and the average $\delta P = 0$. Thus, the well-known double wave in the annual variation of P is eliminated and cannot veil possible relations of the monthly deviations δP to δR and δW. Because of the greater irregular changes in P, the monthly parameters f and g given in Table 3 are smoothed according to $[(a + 2b + c)/4]$. It was, for the present, not thought worth while to improve this definition for P, since the simple formula adopted gives all the relevant monthly variations of P accurately enough, and range-indices, which would be preferable, are not yet available.

TABLE 3—*Parameters for computing monthly mean values of δP from those of u_1*

Value	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
f	0.96	0.99	1.01	0.99	1.15	1.25	1.05	1.03	1.12	1.13	1.17	1.08
g	50	55	59	58	67	69	56	59	73	73	67	56

The result of these standardizations is Table 4. The quarterly and annual deviations given in Table 4 are not simply the averages of the monthly deviations; the averages of the 12 monthly values per year, for

instance, have different standard deviations, namely, 23.8 for δR, 23.3 for δW_1, and 19.2 for δP. Therefore, they were multiplied by (25/23.8) etc., to yield all the annual and quarterly deviations in Table 4 uniformly standardized to $\sigma = 25$.

TABLE 4—*Standardized monthly, quarterly, and annual deviations for solar activity δR, and for geomagnetic data for solar wave-radiation, δW_1, and particle-radiation, δP*

Year	January			February			March			April		
	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP
1922	....	....	....	....	....	....	+ 3	−11	+13	−25	−31	−10
1923	−30	−28	−21	−31	−22	−18	−30	−22	−10	−29	−11	−38
1924	−32	−27	− 1	−29	−27	−29	−31	−28	−32	−25	−24	−34
1925	−29	−13	−17	−18	−29	−14	−21	−20	−23	−12	−11	−27
1926	+14	+10	+38	+13	+16	+35	+ 8	+ 3	+29	− 8	+ 9	+33
1927	+21	+10	+18	+28	+22	− 4	+13	+23	+17	+29	+27	+30
1928	+22	+14	−23	+16	+ 8	−28	+23	+15	− 8	+20	+28	−25
1929	+12	+13	0	+ 9	+24	+40	0	+11	+43	+ 2	+13	− 8
1930	+10	+22	− 4	− 1	+ 8	− 5	−10	+ 8	− 3	− 8	+ 6	− 7
1931	−23	−20	−23	− 5	−19	−15	−13	−18	−26	−12	−17	−18
1932	−25	−33	−27	−25	−28	−27	−25	−17	− 3	−25	−36	−21
1933	−25	−33	−14	−18	−14	−23	−26	−31	−21	−30	−42	−41
1934	−31	−32	−20	−27	−33	−19	−30	−26	− 9	−25	−26	−31
1935	−20	−25	−10	−19	−15	+ 7	−18	−30	−20	−25	−27	−24
1936	+ 8	+13	− 8	+16	+16	− 8	+18	+ 8	−18	+16	+ 7	+ 2
1937	+53	+53	+12	+51	+56	+15	+22	+32	+37	+38	+24	+41
1938	+31	+22	+82	+45	+21	+23	+23	+17	+21	+33	+37	+42
1939	+19	+30	−14	+18	+24	+57	+10	0	+ 8	+38	+24	+43

Year	May			June			July			August		
	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP
1922	−27	−23	−24	−29	−19	−28	−25	−38	−24	−29	−32	−27
1923	−31	−33	−29	−27	−27	−26	−30	−20	−16	−32	−18	−32
1924	−19	−20	+ 7	−17	−18	+12	−14	−29	−14	−20	−21	−34
1925	− 5	−16	+ 1	− 1	0	−10	− 8	− 9	−14	− 8	−17	− 5
1926	+ 9	+23	− 2	+16	+ 7	+24	+ 1	− 2	− 6	+ 8	+14	−12
1927	+19	+13	+ 8	+ 6	+12	−28	+ 3	+ 2	+ 3	+ 3	+ 4	+12
1928	+18	+34	+29	+27	+38	−10	+31	+45	+57	+22	+31	+ 9
1929	+ 5	+ 7	− 6	+14	+ 4	− 8	+13	+18	+12	+10	+ 5	+ 9
1930	− 8	0	+20	−14	0	+14	−18	− 4	−14	−16	−13	−11
1931	−16	−29	−16	−23	−31	− 2	−21	− 5	−28	−24	−21	−21
1932	−21	−20	+ 3	−18	−19	−25	−26	−25	−21	−28	−38	−21
1933	−30	−33	+ 5	−29	−33	−30	−30	−47	−28	−32	−26	− 7
1934	−19	−20	− 5	−28	−19	−21	−27	−29	−23	−27	−30	−29
1935	−15	−13	−16	− 3	−16	− 9	−10	− 7	− 5	−13	− 4	−28
1936	+ 3	+21	− 9	+13	+20	+21	+ 1	+13	+25	+24	+ 1	−15
1937	+43	+40	+43	+52	+48	+41	+62	+52	+39	+57	+60	+49
1938	+50	+31	+51	+31	+19	−10	+75	+48	+44	+45	+30	+28
1939	+44	+37	+40	+33	+38	+19	+31	+50	+41	+36	+47	+62

§ 5. *Relations between δR, δW_1, and δP*

The closeness and linearity of the statistical relations between the monthly values for W and R, with correlation-coefficients approaching unity, have already been discussed in [1] and [2]. That two such arbitrarily defined measures as R and δW_1 should happen to be linked in this way, seems surprising. The correlation-coefficients $r(\delta R, \delta W_1)$ are: For monthly

TABLE 4—Concluded

Year	September			October			November			December		
	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP
1922	−29	−27	− 1	−29	−27	−23	−28	−26	−39	−21	−28	−30
1923	−24	−23	−16	−25	−18	−21	−26	−28	−20	−30	−34	−33
1924	−16	−15	−11	−16	−14	−20	−18	−14	+ 1	−22	− 9	−28
1925	+ 6	+10	+11	+12	+ 8	+10	+ 6	+ 8	− 6	+32	+20	+21
1926	+ 7	+ 7	+31	+14	− 4	+45	+ 6	+10	− 6	+19	+ 5	+16
1927	+12	+11	−28	+ 8	+20	+40	+11	+ 3	− 7	− 3	+ 9	+10
1928	+26	+29	+21	+ 7	+27	+28	0	+ 4	+12	+ 6	+22	−11
1929	−10	+ 3	−10	+ 3	+ 4	0	+20	+ 9	+11	+38	+29	+30
1930	−12	−18	+30	−10	−20	+24	− 9	− 7	+11	−16	−25	+32
1931	−20	−26	−10	−26	−21	+ 6	−20	−24	− 9	−21	−25	−33
1932	−30	−29	−27	−27	−34	−17	−27	−41	−33	−25	−35	−11
1933	−29	−28	−10	−30	−29	−38	−32	−32	−42	−32	−25	−19
1934	−30	−28	−22	−29	−26	−47	−27	−19	−36	−23	−18	− 9
1935	− 5	−15	0	+ 2	−13	− 6	+ 9	+ 1	−13	+ 8	+13	−13
1936	+17	+24	−19	+25	+31	+11	+42	+36	+34	+47	+33	+13
1937	+33	+35	+ 2	+49	+32	+44	+16	+40	+ 6	+25	+33	+28
1938	+26	+24	+36	+32	+32	+36	+47	+35	+21	+28	+42	+44
1939	+41	+27	+24	+25	+30	+44	....	....	....	....	....	....

Year	Quarter, January to March			Quarter, April to June			Quarter, July to September			Quarter, October to December			Annual means		
	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP	δR	δW_1	δP
1922	....	....	....	−28	−25	−23	−29	−34	−19	−27	−28	−35	−29	−30	−28
1923	−31	−25	−18	−30	−25	−36	−30	−21	−24	−28	−27	−28	−31	−25	−29
1924	−32	−29	−23	−21	−21	− 5	−17	−23	−22	−19	−13	−17	−23	−22	−18
1925	−23	−22	−20	− 6	− 9	−13	− 3	− 6	− 2	+17	+12	+11	− 4	− 6	− 7
1926	+12	+10	+42	+ 6	+14	+23	+ 5	+ 7	+ 6	+13	+ 4	+23	+ 9	+ 9	+26
1927	+21	+19	+14	+19	+18	+ 5	+ 6	+ 6	− 4	+ 5	+11	+18	+13	+14	+ 9
1928	+21	+13	−22	+22	+35	− 1	+27	+36	+36	+ 4	+18	+13	+19	+26	+ 7
1929	+ 7	+17	+34	+ 7	+ 8	− 8	+ 4	+ 9	+ 6	+21	+14	+17	+10	+12	+13
1930	0	+13	− 4	−10	+ 2	+12	−16	−12	+ 3	−12	−18	+28	−10	− 4	+11
1931	−14	−20	−24	−18	−27	−13	−22	−18	−22	−23	−24	−13	−20	−23	−20
1932	−26	−27	−21	−22	−26	−16	−29	−32	−26	−27	−38	−23	−27	−32	−23
1933	−24	−27	−22	−31	−37	−25	−31	−35	−17	−32	−29	−38	−31	−33	−28
1934	−30	−32	−18	−25	−23	−21	−29	−30	−28	−27	−21	−35	−29	−27	−28
1935	−20	−24	− 8	−15	−19	−18	−10	− 9	−12	+ 7	0	−12	−10	−13	−14
1936	+14	+13	−12	+11	+17	+ 7	+14	+13	− 2	+39	+34	+24	+20	+20	+ 5
1937	+43	+49	+27	+46	+39	+51	+52	+51	+37	+31	+36	+32	+45	+45	+40
1938	+34	+21	+51	+39	+30	+34	+49	+35	+44	+37	+37	+41	+41	+32	+46
1939	+16	+19	+21	+40	+34	+42	+37	+43	+52	+19	....	+19	+32	+33	+42

NOTE: The "annual means" for the years 1922 and 1937 are computed from ten months only.

averages, $+0.930$; for quarterly averages, $+0.969$; and for annual averages, $+0.988$. The increase of r with lengthening intervals illustrates typical statistical properties of geophysical time-series discussed in [6].

Scatter diagrams (point-clouds) reproduced in [2], with δR as abscissa, δW_1 or δP as ordinates, show clearly how much more closely δW_1 is related to R than P. The correlation-coefficients $r(\delta R, \delta P)$, 1922 to 1939, are: For monthly averages, $+0.724$; for quarterly averages, $+0.860$; and for annual averages, $+0.942$. The correlation-coefficients $r(\delta W_1, \delta P)$ are even a little smaller for quarterly averages, namely, $+0.846$, and for annual averages, $+0.932$.

The small scattering in the point-clouds (δR, δW_1), with the ensuing smallness of the divergences between the various regression-lines, alleviated the choice of the constants for, and narrowed the arbitrariness in, the definition of δW_1. The statistical reasoning underlying the procedure adopted in § 4 will be discussed somewhere else. But it should be mentioned that the idea of standardizing geophysical time-series to suitably chosen standard deviations is due to Sir Gilbert Walker and E. W. Bliss [7]; they chose, for the rather vague meteorological correlations, $\sigma = \sqrt{20}$; in our case, the greater exactness of the δW_1-values indicated $\sigma = 25$ as suitable numerical value for the standard deviation, in order to express the time-series accurately as well as conveniently in integers of one or two digits, namely, hardly ever surpassing $4\sigma = 100$.

The error-limits of the correlation-coefficients are discussed in the Appendix, § A4. A slight curvature in the average relation between R and W, noticeable for high values of R, will be discussed in § 16*e*.

§ 6. *Correlations in changes from month to month*

The high correlation-coefficients $r(\delta R, \delta W_1)$ must not be misconceived as meaning that the two time-series for R and W are practically identical. For, even in the best regression-equations for δW_1 as linear functions of δR, splitting δW_1 into a "parallel" part varying proportionally to δR, and an "orthogonal" residual, the standard deviations of the remaining residuals reach a considerable percentage of those of the parallel parts, namely, 40 per cent for monthly means, 26 per cent for quarterly means, and 16 per cent for annual means. In this respect, significant discrepancies have already been pointed out [1], for instance, the epochs of the sunspot-maxima in 1928 and 1937 are more marked in W than in R.

Another feature in the statistical relation between the two time-series for R and δW_1 is shown by considering the changes from month to month, that is, from March, 1922, to April, 1922, etc. In these, the correlation between δW_1 and R is much less distinct than in the monthly values themselves. The material was divided into two groups, namely "minimum," with few sunspots (comprising the 106 changes up to the months May, 1922, until August, 1925, and April, 1930, to September, 1935), and "maximum," with many sunspots (comprising the 105 changes up to the remaining months). The standard deviations of the intermonthly changes in the two groups are in δR, 4.9 and 13.7, (corresponding to about 8 and 21 units of the sunspot-number R), that is, quite different, but in δW_1, 8.8 and 11.7, less different. Now, the correlation-coefficients between the intermonthly changes are, in the two groups, +0.07 for "minimum," and +0.42 for "maximum." This contrast between sunspot-minimum and maximum appears also in the point-clouds reproduced in [2].

This means that the high correlations between the monthly values of

δR and δW_1 in Table 4 are mainly caused by the large 11-year cycle which runs parallel in both; the superposed shorter variations are, however, less parallel, the intermonthly changes being practically independent in times of few sunspots, and only loosely connected in times with many sunspots.

The significance of this result seems, however, more statistical than physical: The average Zürich sunspot-number R changes little from month to month—only about eight units in the minimum group. Considering the uncertainty of δW_1, especially of the shift, from month to month, of the parameters in Table 2, it seems hardly justified to expect such small changes in R to be accurately reflected in δW_1, at least not in individual cases.

§ 7. *Retrospect*

Before the results described above had been found, our knowledge of the change of W and P with R in the sunspot-cycle, as summarized in "Geomagnetism" [3], was mainly restricted to the fact, confirmed in many papers, that both W and P varied in unison with R, with a distinct lag of the maximum phase in P. But while there had been available fairly homogeneous series expressing the variations of P, analogous series for W have for the first time been derived here. Thus it could be demonstrated how much more closely W is related to R than P; and P *is dethroned by* W *as the geophysical phenomenon with the clearest connection to solar activity.*

Incidentally, the close relationship found lends mutual support to R, as a measure for solar activity, as well as to δW_1, as a measure for the intensity of S_q, and those who realize how many snares may beset the management of magnetic observatories, will acknowledge the implicit proof for the unchanging quality of the Huancayo magnetic records.

However, the monthly means for W gave not yet sufficiently accurate indication how quickly W reacts to changes in solar activity. M. Waldmeier, using ionospheric data, concluded, in a paper that appeared in a recent volume of *Helvetica Physica Acta*, not now accessible to me, that W might lag behind R by several months. Values for W for smaller time-intervals, such as days, seemed desirable to settle this question, as well as the other one whether in W there is a counterpart to the famous 27-day recurrence-tendency in P. After a few indications published in 1941 [2], it could be stated with certainty before the Berlin Academy, early in 1944, that the variations of W are parallel to those of R, no time-lag longer than a day being recognizable. Also, a 27-day recurrence-tendency was shown to appear in W as clearly as in R, and parallel to that in R; it differs therefore from that in P, where it was shown (see part II of this paper) to be weak in the ascending part of the 11-year cycle, but much stronger than in R, and independent of it, in the years preceding sunspot-minimum. Diagrams in red and black, demonstrating these facts rotation by rotation, for the years 1922 to 1937, were printed as advance copies to accompany further parts

of the "Schwankungen" [2] now lost; samples are reproduced here in Figure 4 (§ 17).

§ 8. *Daily values δW_2 for W*

Daily values of δW_2 for W were computed from A_S with similar formulas as in § 4. From the monthly average parameters in Table 2, daily

TABLE 5—*Daily values, May 1922 to December 1937, for solar wave-radiation δW_2 expressed in deviations (with standard deviation = 10) from a normal value assumed for sunspot-number R = 50 [Letters p and P signify possibility of moderate or heavy error in δW_2 due to simultaneous particle-radiation (§ 3)]*

Day	1922											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	......	......	......	......	+1	+9	+6p	−11	−25	−16	−12p	−12
2	......	......	......	......	+6	−6	−18	+1	−13	−10	−7p	−18
3	......	......	......	......	−8	−14	−9	−19	−24	−6	−9p	−15
4	......	......	......	......	−14	−7	−9	+2	−20	+1	−2	−16
5	......	......	......	......	−20	−14p	−21	+2	−15	(= P)	−5	−6
6	......	......	......	......	−12	+4	−15	−13	−25	−9p	−9	−17
7	......	......	......	......	−18p	−12	−14	−14	−25p	−11p	−13	−17
8	......	......	......	......	−27p	−2	−8	−6	−27p	−8	−6	−2
9	......	......	......	......	−17p	−11	−10	−4	−25p	−7	−8	±0
10	......	......	......	−30p	−7	−9	−2	−10	−26	−6	−4	−5
11	......	......	......	±0	−6	−7	−15	−51P	−11	−11	−20	−11
12	......	......	......	−3p	−1	−21	+1	−10p	−10	−20	−2	−6
13	......	......	......	+7	+4	−9	−7	−7p	−2	−15	−6	−8
14	......	......	......	−5	−7	−10	−19	−29p	(= P)	−13	±0	−7
15	......	......	......	−20	−5	−10	−13	−26	−9	−1	−32	−14
16	......	......	......	−14	±0p	+8p	−24p	−19	−9	−1	±0	−7
17	......	......	......	−18	−16	−7	−22	−14	−17	−13	−8	−10
18	......	......	......	−3	−11	+7	−9	−10	−11	−14	−22	−3
19	......	......	......	−1	+5	−4	−25	−25	−5	−11	−3	−3
20	......	......	......	−3	−5	−19	−9	−33	−20p	−27	−22	−10
21	......	......	......	−24	−5p	−7	−16	−14	−11	−10	−13	−9
22	......	......	......	−28p	+4	±0	−16	−13	+7	−1	−17	−11
23	......	......	......	−15	−14	−16	+2	−11p	−1	−7	−7	−26
24	......	......	......	−19p	−19	±0	−24	−10	±0	−26	−4	−15
25	......	......	......	±0	−13	−20	−10	−4	−6	−15	−18	−15
26	......	......	......	−3p	−31	−2	−40p	−24	−10	−17	−7	−34p
27	......	......	......	−11	−1	−21	−18p	−20	−10	−16	−6	−18
28	......	......	......	−12	+4	−12	−5	−19	−6	+5	−19	−11
29	......		......	−30	−13	−19p	−11	−16	−2	−15	−15p	−8
30	......		......	−3	−21	−8p	+12	−18	−14	−9	−2	−26
31	......		......		−5		−27	−14		−20p		−13

TABLE 5—Continued

Day	1923											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	−6	−21	−17	+4	−4	−11	−16	−24	−22	−2	+8	−10
2	−20	−18	−11	+7	−13	−10	−18	−9	−13	−7	−13p	−16
3	−9	......	−10	±0	−13	−24	−4	+9	±0	−12	−27	−23
4	+3	+5	−14	+5	−18	−11	−14	−1	−6	−6	−12	−8
5	−5	−2	−1	−14	−22	−6	+2	−6	−32	−8	−9	−21
6	−19	−6	−11	+1	−12	−21	−9	+1	−15	+5	+2	−11
7	−16	−17	−18	−22	−3	−22	+7	+8	−20	−9	−10	−28
8	−25	−13	−17	±0	−3	−22	−6	−12	−23	−14	−12	−20
9	−8	−3	−11	−5	−13	−32	−7	−10	−3	−14	−24	−29
10	−10	−18	−10	−1	−8	−20	−12	−16	−7	−6	−11	−18
11	−26	−13	−11	−2	−9	−25	+4	−16	+6	−24	−4	−8
12	+1	−20	−10	−6	−8	−10	−13	−18	−2	+1	+3	−13
13	−14	−8	−7	−2	+1	−18p	−4	+9	−13	−8	−7	−12
14	−9	+3	−2	−2	−20	−18	+1	−20	−5	+3	−5	−11
15	−31	−20	−3	−3	±0	−1	+4	−12	−5	−32P	−18	−14
16	−15	−3	−15	±0	−3	−6	−26	−5	+1	−46P	−21	−18
17	−23	−7	−16	−4	−10p	−9	−18	−26	−1	−26p	−24	+2
18	−12	−7	−13	−3	−23p	−7	−4	−4	−10	−8	−9	−16
19	−4	−12	−14	+9	−15	+14	−19	+6	−12	+5	−19	−11
20	−13p	−15	−5	−11	−2	+4	−12	−23	−21	+2	−9	−10
21	−18	+7	−9	−17p	−14	−9	−9	−7	−22	−8	−17	−9
22	+5	−7	−14	−12	−5	−17	±0	−14	−13	−12	−22	−18
23	−16	+5	−12	−2	−21	−15	−13	−9	−7	−22	−6	±0
24	+4	−7	−29P	−1	−22	−19	−9	−5	−3	+1	......	−28
25	+1	−14P	−21p	+5	−8	−9	−1	−5	−4	+5	......	−19
26	+2	−9p	−10	−3	−29	−19	+2	−27	−3p	−9	−17	−5p
27	−1	−18p	−10	−11	−18	−7	+9	+3	−25P	−18	−31	−20
28	−8	−9	−2	−20	−27	+5	−6	−8	−3	−17	−9	−5
29	−15		+3	−34	−36p	+3	+2	−8	+8	−16	−10	−9
30	−5		−2	−4	−32	−53p	−10	−2	−3	−9	−5	−4
31	−10		−2		−3		−13	−18		+7		+2

values for ω_1 and $A_{S;R=50}$ were derived by simple graphical interpolation. Because daily values are less accurate than monthly averages, it was thought sufficient to express δW_2 in integers with the smaller standard deviation $\sigma(\delta W_2) = 10$; the interpolated values of ω_1 were therefore multiplied by $(10/25) = 0.4$ to obtain ω_2.

Values of δW_2 are given in Table 5. The daily series ends 1937, because the sheets of hourly values of H, from which the monthly averages of A_S up to October, 1939, had been computed, were no longer available.

Table 5—Continued

Day	1924											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+ 1	− 1	− 3	− 7	−15	− 9	−15	−26	−10	− 6	+12	− 4
2	− 3	−16	......	−20	− 4	+ 6	+ 1	+ 8	+ 4	− 8	− 6	−21
3	− 9	− 3	−11	−14	− 2	− 6	−19	− 8	−22	− 6	−11	− 5
4	− 9	− 5	−12	− 5	− 6	−13	+ 5	+ 2	− 7	− 3	−23	− 2
5	−16	−11	−26	−14	−12	+17	+ 1	+ 7	− 1	−10	−13	− 5
6	± 0	......	−21	− 8	−16	− 6	+ 2	−22	− 6	− 8	− 1	+ 6
7	− 5	− 7	−12	−17	−16	− 5	+ 4	−10	− 9*P*	+ 5	+ 1	+ 2
8	−12	− 7	−13	−17	+ 3	+ 4	− 6	−25	−13*p*	+ 1	− 7	−16
9	− 1	− 4	−16	−10	−10	−16	− 9	+ 1	− 6	− 8	− 7	− 1
10	−28*p*	− 2	−17	−14	−10	−79*P*	−13	−11	−17	−14	+ 2	−10
11	−16	− 9	−11	−10	− 3	+ 8*p*	+ 9	+ 5	−11	− 6	−17	− 1
12	−27	−11	−18	−15	−15	−18	+ 5	−15	− 6	− 1	−10	+ 8*p*
13	−21	− 4	−12	− 9	−10	+ 8	− 4	−24	± 0	− 1	−20	+ 2
14	−23	− 7	−10	− 1	−10	......	− 6	+10	−20	+10	− 5	+ 1
15	− 8	−11	− 8	− 5	± 0	−20	− 9	−24	−15	± 0	− 5	+ 8
16	− 3	− 9	−14	−11	+ 2	− 6	− 7	−21	−11	− 2	+ 2	+ 4
17	+ 2	−23	−13	− 9	− 6	−11	−19	+ 1	− 5	− 1	−12	+ 2
18	−11	−25	−11	− 6	−14	− 4	−21	......	+ 7	−29	− 6	+10
19	−28	−14	−10	−12	−22	−52*P*	−35	− 1	− 3	−10	−22*p*	− 6
20	− 9	−40*p*	− 9	± 0	−10	− 5	+ 2	+ 9	−16	− 3	+ 8	+13*p*
21	− 3	−16	−21	+ 1	− 8*p*	− 1	−20	......	−14	± 0	+ 5	± 0*p*
22	−16	−21	−15	+14	−35*P*	− 7	−12	− 7	− 8	− 1	−14	−18
23	− 7	......	−12	+ 9	−14*p*	−24	−13	−25	+14	−20*p*	− 4	− 5
24	− 5	−10	−20	− 3	− 8	− 4	−19	− 7	+ 6	−14*p*	−43*P*	−13
25	− 8	−15	− 3	−30*p*	− 6	−15	−27	− 6	± 0	−17	+ 4	−17
26	−16	−15	−19	−35*p*	− 6	− 7	−27*p*	−16	+ 1	−10	+ 2	−20
27	− 5	−23	− 9	−14	+ 2	−16	− 5*p*	+ 2	− 9*p*	+ 2	−21	− 3
28	− 2	− 9	−17	−21	−26*p*	−15	−15	−21	− 5	− 7	− 7	+10
29	± 0*P*	−16	− 4	− 3	+ 8	− 9	−18	−20	+ 5	− 5	−12	+ 5
30	−14*p*		−10*p*	−20	− 7	−14	− 6	− 4	− 4	−11	− 8	+ 6
31	−12		− 5		− 9		− 6	− 6		+ 2		+ 6

§ 9. *Eighth-values for* R, W, *and* P

In the course of trial calculations, it appeared advisable to increase the accuracy of the δW_2-values by averaging over several consecutive days. The exact 27-day solar rotations used by the author [3] to demonstrate the recurrence-tendency in P were chosen as convenient basis for time-intervals; each rotation was divided into eighths, of (27/8)-day duration each, and named *a*, *b*, . . . , *h*. For instance, rotation No. 1420 runs from January 1

TABLE 5—Continued

Day	1925											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+ 4	-20	-36	+ 6	- 7	- 7	- 3	- 7	+25*P*	+ 4	+12	+12
2	+10	- 5	-13	+ 1.	......	-17	- 2	-16	+ 4*p*	......	+ 3	+ 1
3	-21	-12	- 3	-24	- 4	-10	......	- 2	+16	+ 8	- 8	+ 2
4	-10	-28	+ 3	- 8	-23*P*	+ 3	- 4	-25	+11	- 3	- 3	- 4
5	- 8	-11	- 8	-10	-12	-16	+ 1	+ 2	+ 1	+13	+ 9	+ 2
6	-10	- 7	-11	- 9	- 8	- 1	± 0	-12	+ 5	- 5	......	-31*p*
7	- 3	-11	-19	- 6	- 7	+ 5	+10	-34*p*	-14	- 9	......	- 1
8	+ 8	-19	-19	+ 1	+ 1	- 2	-11	-11*p*	- 8	+ 8	- 8	- 3
9	± 0	-16*p*	-15	- 4	+ 1	+ 8	+ 1	- 8	-14	- 6*p*	- 3*P*	± 0
10	+ 6	-11	-12	-11	- 5	± 0	+ 8	+ 4	+ 2	+ 6	- 2	+ 2
11	+ 9	- 5	- 6	- 6	+ 5	+ 8	+ 5	-15	+ 4	- 4	+14	+16
12	+ 4	-14	- 5	- 8	+11	+ 8	+16	-10	-17	+ 8	± 0	+18
13	+ 5	+ 5	- 2	+ 5	+ 1	-24*P*	+16	+ 7	- 3	+15	- 2	+ 7
14	- 2	-14	+ 3	+ 2	-11	- 1	+ 1	- 1	-10*P*	+13	-11*p*	+30
15	+ 3	- 6	-12*p*	- 6	-13	+ 1	- 4*p*	- 1	-15*p*	+12	+ 5	+ 4
16	......	- 4	+ 2	+ 6	-31	+12	-14	+16	± 0	± 0	+13	+24
17	- 5	-20	- 3	- 8	-17	- 3	-21	-11	- 9	+ 4	- 1	......
18	- 2	-23	- 9	+ 8	- 1	- 2	+ 1	-32	+ 4	......	+ 7	-18
19	-17*P*	-31	- 5	+ 8	± 0	- 2	-17	-21	+ 7	......	+16	+24
20	+ 1	-23	-17	......	......	- 6	- 6	......	+11	......	+ 6	+12
21	± 0	-14	-17	-12	- 3	- 1	-20	-16	+20*P*	......	- 9	+ 6
22	- 3	-11	-12	- 8	-10	+ 4	- 7	+ 3*p*	+12	......	+ 4	+ 7
23	- 4	-11	- 9	+ 6	+ 6	-24*p*	- 9	-16*p*	+16	......	+ 4	+11
24	- 8	- 2	± 0	± 0	-10	+ 6*P*	- 5	-18	+ 5*P*	+ 4*p*	+12	+11
25	-19	- 2	-18	- 1	- 4	-22*p*	+ 4	- 4	+10	+24	+ 2	-10
26	- 5	-11	+ 2	- 7	- 6	+11	- 7*p*	......	+ 6	+10	- 6	+ 7
27	+ 5	-20	- 9	-10	-35	- 5	- 2	-13	+20	- 5	+ 7	+19
28	-13	-14	- 6	± 0	- 1*p*	- 2	-12	-19	+21	- 7	+ 2	+14*p*
29	-26		- 6	+ 2	+ 7	+11	-18	- 8	+ 5	- 4	- 1	+18
30	-27		-24	-13	+ 3	......	± 0	......	+16	+ 9	+ 6	+26
31	-18		-10		-25*p*		+ 1	+20		+ 2		+10

to 27, 1937. In order to calculate the eighth-values 1420*a* and *b* for δW_2 from Table 5, the value +13 for January 4 must be divided into 3/8 and 5/8, that is, into +5 and +8; thus, the eighth-value for 1420*a* becomes (8/27)(+37 + 31 + 22 + 5) = +28; that for 1420*b* becomes (8/27)(+8 + 23 + 21 + 21) = + 22; etc. By suitable interpolation, it is possible to bridge the gaps in the daily values δW_2 caused by days marked *P* or lost on the records, so that an unbroken series of eighth-values for δW_2 could be

Table 5—Continued

Day	1926											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	−8	+7	−6	+2	−14	+3*P*	+9	+11	−2	−10	+7	−7
2	+24	+9	−6	+17	+5	−12*P*	−11	+12	−4	−3	+9	−4
3	−3	+13	+12	+11	+7	+8	+6	+11	−4	−9	+1	+3
4	+8	+9	+9	+11	−7*P*	+21	−28	+10	−9	−2	+1	......
5	+8	+11	−22*P*	+18	+5*p*	+1	−9	+9	+12	+3	+9	+8
6	+5	+12	+2*p*	+5*p*	+10	+4	+1	+4	+8	+5	±0	−9
7	+6	−4	+13	+7	+6	+2	−1	+24	+1	−7	+3	−1
8	−7	+5	+14	±0	+14	+12*p*	+7	+10	−21*P*	+3	+10	−7
9	+2	+4	+11*p*	−4	+29	+13	−3	−16	+12*p*	+21	−14	−8
10	−9	+11	+17*p*	+13	+8*p*	−11	−10	......	+4	+12	±0	−7
11	−1	−12	−5*p*	+2	+9	+11	−19	+7	−8	±0	+9	−28
12	+8	+8	+5	+7	+10	−12	+24	+20	−2	+10	+8	+1
13	+15*p*	+3	+10	+18	+27	+4	+1	−2*p*	+2	+12	+3	−1
14	−1*p*	+15	−11	+3*P*	+7	−14	−11	+13	−15*p*	+5*p*	+18	−8
15	+15	+16	+8	......	+29	−11	−9	+10	−7*P*	+5*P*	+7	±0
16	+12	−1	+18	+22*p*	+19	−4	−3	+1	−6	+26*P*	+5	−1
17	+12	+27	+6	+3	+21	+2	+9	−14	+17	+13	−20	+15
18	+13	+20*p*	−22	+2	+10	+13	±0	−20	+11	−4	−3	+20
19	+1	+14	+4	+12	+26	−7	−21	−3	+13*p*	−3*p*	−17	+18
20	+23	±0	−5	+18	+14	+9	−6	+12	−6*p*	+5	+10	+24
21	+18	−8	+4	+22	+10	+24	±0	−2	−19*P*	−15	+9	+5
22	+24*P*	+2	−2	−15	+6	−19	+3	+23	+18	−2	+8	+8
23	+25*p*	+22*p*	−9	+6	+3	+18	+16	−1	+9	±0	+6	−30*P*
24	−2	−56*P*	−9	−2	+8	+3	+20	+4	+8	+1	−12	±0
25	−3	+21*p*	+3	−9	−9	+8	−16	+2	+3	−18*p*	−14	+10
26	......	+13	−1	+9	+7	−7	±0	−5	+11	−10	+9	+7
27	+14*p*	+19	+8	−16	−12	−2	+24	−3	......	−10	+9	+12
28	+15	−5	+2	−4	+2	+15	+17	−1	+1	−16	+9	+1
29	+1		−11	−12	+4	+1	−5	+14	−9	−19	+5*p*	−1
30	+16		+1	−9	−2	+3	−4	+6	+6	−5	+9	+4
31	−9		−4		+9		−22	+2		+4		+4

obtained for rotations No. 1221 (day 1 = April 17, 1922) to No. 1432 (day 1 = November 21, 1937).

The formation of eighth-values for the purpose of comparing W with R may be justified as follows: Those short-period variations which are to be investigated are likely to be found when, in the course of the Sun's 27-day rotation, highly active areas alternate on the Sun's disk with a relatively quiet hemisphere (bounded by meridians), that is, when solar activity

TABLE 5—Continued

Day	1927											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	− 8p	−24	− 3p	+ 7	+ 5	+34	− 3	− 8	− 2	+ 2	+ 5	− 7
2	+ 4	−14	− 3	+ 5	−11	− 1	+19	− 3	− 9	+ 8	− 4	+ 5
3	+12	+ 3	+25	± 0	−10	+12	−17	+14	− 5	− 2	+ 2	+ 6
4	+10p	− 5	+32	+ 6	+12	+12	+ 9	+ 3	−20p	+15	± 0	− 1
5	− 8	+ 6	+16	+18	+ 8P	− 6	+10	− 5	− 1	+23	+ 2	± 0
6	− 5	+37	+ 7	+23	+ 4	+21	+16	− 5	+ 6	+14	−20	± 0
7	−10P	+35	+ 3	+11	−40P	+16	−21	+10	− 7p	+12p	± 0	+ 1
8	− 2	+22	+ 7	−10	+10	+18	− 9	−12	± 0p	+10	− 3	+11
9	+12	+22p	+ 7	−19p	+ 5	− 7	− 1	+15	− 6p	+ 4	+ 9	+ 8
10	......	+15p	+14	± 0	− 4	+13	+ 9	− 9	−10p	+ 9p	± 0	− 2
11	−11	+ 5	+14	− 6p	+14	− 8	− 8	− 2	− 4	+14	+ 8	+ 8
12	+21	+ 5	+18	+20	+21	− 2	+ 6	+ 4	+ 1	−69P	+23	+10
13	+13	+ 2	+ 8	+22	+17	+ 4	+ 5	+ 1	+13	+13p	− 8	−23P
14	+25	+23	− 5	−39P	+13	± 0	− 1	−10	+23	+25	− 5	+15p
15	−15	+16	+11	+16	+10	+ 9	− 9	− 3	+17	+25	+ 6	+14p
16	+ 9	+16	± 0P	+16	+11	+ 5	+ 8	−22	+ 9	+27	+10	+ 4
17	−16	+12	+18p	+18	+ 2	− 1	−20	+14	+ 6	+17	+22	− 6p
18	+21	+ 3	+ 9	+14	......	+ 8	+21	− 2	+ 4	+15	−16p	−20p
19	± 0	± 0	− 2	+14	+ 2	−13	− 2	+ 4	− 4	− 1	+ 1	+ 7
20	+23	− 6	− 5	+14	−20p	+17	−12	+15p	+ 6	− 1	− 6	+ 6
21	......	+ 2	+ 4	± 0	+ 9	+ 4	− 7	−21P	+11	+ 4	− 2	+13
22	......	+ 6	+14	+11	+10	−18	−19P	+19	+12	−47P	+ 7	− 4
23	+ 9	+15	+33	+12	+16	± 0	+ 4	+ 8	+ 8	−10p	− 6	+ 6
24	+ 8	−19p	+15	+ 4p	+13	+ 2	+ 9	+ 6	+ 2	+24	+ 3	+ 2
25	− 4	+14	+ 9	......	− 4	+ 1	− 7	− 3	± 0	+ 7	− 9	+ 5
26	−20	+18	−27P	......	+ 6	−10	− 5	+ 7	+ 8	+ 3	+ 4	−10
27	± 0	+14	+13P	+ 7	+ 8	− 2	− 3	+26	+19	− 4	− 7	+11
28	+ 1	+17	− 2p	+24	− 1	+ 4	+ 1	+ 4	+ 8	−20	− 9	+20
29	+ 7		+16	+27	− 1	+11	+11	+14	− 7	± 0	± 0	+ 3
30	......		+ 4	+ 5	+10	+22	+ 4	−30p	− 2	+ 8	+ 9	+12
31	+ 5		+17		+ 1		− 8	+ 2		+14		+12

changes much with heliographic longitude. Thus, in the rotations No. 1417 to 1421 (see Table 5), high sunspot-numbers, up to $R = 233$, prevailed in the weeks around the beginnings and the ends of the rotation-intervals, alternating with low sunspot-numbers, down to $R = 20$, observed in the middle of these intervals. This contrast of the hemispheres, given by the daily values R, appears quite as clearly in averages for eighths of rotations, formed as for δW_2.

Table 5—Continued

Day	1928											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+20	+22	− 6	− 9	+16	+30	+36	......	− 3	+ 7	+23	+ 7
2	+21	+ 9	− 3	−10	+31	+27	− 9	+ 4	+16	− 3	± 0p	+10
3	+14	− 1	+13	+ 4	+13	+16	+ 2	+22	+ 7	+21	− 3P	− 3
4	− 6	± 0	+13	+12	+18	− 1	+33	+10	+30	+27	−12	+16
5	+32	−18	+16	+24	+33p	+29	+ 8	+ 6P	+ 8	+ 9	−12	+12
6	+24	− 1	− 2	+10	− 3	+25	+ 3	+30	+ 4	+24	− 3	+ 9p
7	+14	− 3	− 1	+10	+ 6	− 8	+33	− 3	−11P	+ 5	− 2	+11
8	+ 8	− 6	+ 7	+ 2	+15	+ 3	+97P	+19	− 6p	+15	+ 6	+16
9	+12	− 3	+ 8	+ 9	+32	− 2	+ 5p	+18	− 3	+ 8	+ 8	+20
10	+18	− 2	+18	+ 4	+ 9p	+16	+ 8	+26	+ 1	+38	−33p	+23
11	+ 2	+ 9	−39P	+10	+ 4p	+ 8	−22	+20	− 5	+16	+11p	+27
12	−10	+ 2	+ 5p	+18	+ 2p	+ 9	+16	+13	+ 9	+17	+19	+16
13	− 6	− 3	− 5p	+ 2	+22	− 1	+15	− 3	+18	+10	+ 4	+ 8
14	−18	+ 2	+13	+27	+18	− 7	− 8	+ 9	+ 8	+ 5	+18	+ 8
15	+ 5	+ 6	+25	+42	− 3	+23	+ 2	+18	+ 9	+10	+ 6p	+14
16	− 5	+11	+ 6	+26	+17	+ 4	+ 5	+ 4	+ 9	+11	± 0p	+ 5
17	− 8	+ 6	± 0	+ 7	+ 7	+20	+ 1	− 5	+ 3	+13	+ 2p	± 0
18	−10	+ 9	+ 8	+10	+ 3	+17	+20	+13	+29	−49P	+10	+11
19	+ 6	+11	+11	+17	+ 6	+11	+23	− 1	+11	+23p	+11	+11
20	−14	+10	+16	+13	+ 5	+35	+28	+ 4	+18	+26	+ 4	+17
21	− 2	−12	± 0	+11	+ 5	+ 4	+44	+21	+29	+13	+ 3	−11
22	− 4	± 0	+ 9	+15	− 6	−11P	+39	+ 7	+23	− 3	− 3	......
23	− 6	+ 7	+ 7	+13	+ 5	+28p	+28	+22	+18	+ 8	−14	......
24	+ 4	+22	+13	+15	+21	+19	+58	+21	+11	+18p	−19	−18
25	+ 5	+ 9	+ 8	+ 7	−12	+28	+25	+ 1	−20P	+24P	− 5	+18
26	+13	+ 1	+ 6	+ 2	+22	+14	+ 7	+21p	+ 6	+ 9	− 2	−18
27	− 4p	+21	+ 5	+ 6	+10P	+42	+ 4	+ 8p	+15	+ 6	± 0	+ 4
28	+11	−11	+ 4	+13	− 3P	+30	+ 7	+25	+35	+ 4	± 0	−15
29	+30	+ 2	+11	+26	− 5p	+32	± 0	− 1	+33	± 0	+ 2	+18
30	+12		+ 1	+27	+27	+37	+20	+12	+10	± 0	+ 2	+10
31	+ 8		+ 7		+43		+13	+16		+ 9		+ 5

These eighth-values are given in Table 6, not for the original sunspot-numbers R, but for $(R/5)$, as in the tables in volume 2 of "Geomagnetism" [3], where $(R/5) = 0$ is written for $R = 0$, $(R/5) = 1$ for $R = 1$ to 5, $(R/5) = 2$ for $R = 6$ to 10, etc.; the average for all values R which lead to the same value for $(R/5)$ is 5 times $(R/5)$, minus 2, except, of course, for $(R/5) = 0$.

As counterpart to δW_2, the international magnetic character-figure

TABLE 5—Continued

Day	1929											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+20	+17	+20	+ 1	+18	+ 2	+33	−32P	± 0	+10	−19p	+17
2	− 2	+18	− 5	+ 9	+ 3	− 3	+20	± 0	+ 2	+16	− 9p	+21
3	+ 6	+17	−12	+ 1	+18	− 3	+17	− 2	− 3	+ 8	+ 2P	+15p
4	+23	+13	−10	+14p	− 9	− 9	+ 1	+15	− 2	+ 5	+20p	−24p
5	+17p	+23	+ 5	+18	+ 2	−14	+26p	± 0	+ 3	+ 8	+ 8p	± 0p
6	+ 4	−12p	+ 6	+12	+16	+ 8	+ 5	− 8	−11	+13	+ 3p	+ 9p
7	− 4	+10	+ 8	+ 1	+16	+14	+16	+ 3	−11p	−12P	− 3p	− 3
8	......	+13	− 8p	−11	+10	+ 6	+23	+ 5	+14	+ 5P	+ 7	± 0
9	± 0p	+ 5p	+ 1	− 6	− 7	+17	− 1	− 1	+23	± 0p	− 6	......
10	+10	+13	+18	+ 9	+ 5	+ 2p	+ 6P	+ 6	+ 5p	+14	+15	+ 7
11	+ 5	+ 1	+28	± 0	− 5	+28p	− 7	+ 6p	− 3p	+19	......	+ 8
12	+ 3	− 5	−24P	+19	+17	+13	+ 7	+12	− 7p	± 0	+12	+ 5
13	+22	+16	± 0	− 4	+21p	+ 5	− 5	−27	± 0	+ 8	+ 5	− 3
14	− 9	− 4	+11	+ 7	+ 8	−17	+ 8	− 6P	−15p	+ 8	+ 6	+25
15	− 1	+ 4	− 6P	+15	− 3	+ 9	+21p	+ 9p	+ 1	+13	+11	+ 9
16	−12	+11	± 0p	+ 1p	± 0	− 1	−31p	− 3	+ 2	+ 1P	−10p	−29P
17	+ 2	−17P	+10	± 0p	− 7	+ 9	− 5	+10	+ 6	− 1p	+ 8	+24p
18	+ 1	+18p	+ 8	− 5	+ 1	− 6	+13	+19p	− 1	− 1p	− 3	+24
19	+ 9	+ 2p	+ 8	+ 2	−11	+ 7	± 0	− 9	+12	+ 4p	+ 1	+24
20	+18	+11	+ 5	+26	+ 8	+ 9	− 5	+13	− 1	+10	−14	+21
21	+14	+14	+14p	+14	− 9	+ 9	+ 5	+ 6	− 8	− 4	+11	+11
22	+ 9	+ 7	+ 8	+ 3	+12	+14	− 9	+ 7	− 3p	− 6	+17	−13p
23	+ 8	+ 9	+12	+ 8	− 8	+ 1p	+ 4	+17	+ 9	−10	− 3	+27
24	+ 8	+11	+ 5	− 5	+ 8	− 8	+ 7	− 4	± 0	−20	+13	+18
25	− 8	+ 9	+ 7	+20	+ 1	+ 2	− 1	+ 3	+13	−11	−14	+32
26	± 0	± 0	+12	+10	+ 3	+11	+ 2	+20	+ 4	−17	+ 9	+11
27	− 3	−24P	+10	+17	+12	− 8	+ 5	+ 1	− 7	− 6	+ 4	−10
28	+24	+13p	+12	− 3	+ 5	−29	+ 6	−13	− 9	− 2	−11	+12
29	−10		+ 6	−15	− 7	+24	+ 6	+10	+ 3	+ 8	+15	+ 8
30	+ 2		+ 3	+16	+ 3	−15	+ 2	−16	− 4	−11p	+25	− 5
31	+ 6		+ 6		− 5		+10	−18		−15		+11

C_{int} offers itself as daily measure for P. It is likewise simplified by defining a scale C_8 of one digit, as follows: $C_8 = 0$ for $C_{int} = 0.0$ and 0.1; $C_8 = 1$ for $C_{int} = 0.2$ and 0.3, etc.; $C_8 = 4$ for $C_{int} = 0.8$ and 0.9; $C_8 = 5$ for $C_{int} = 1.0, 1.1, 1.2$; $C_8 = 6$ for $C_{int} = 1.3, 1.4, 1.5$; $C_8 = 7$ for $C_{int} = 1.6, 1.7, 1.8$; $C_8 = 8$ for $C_{int} = 1.9$ and 2.0. The C_8-scale preserves, for many statistical purposes, the salient information about P expressed in C_{int}, while saving computing labor.

TABLE 5—Continued

Day	1930											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+17	+11	−21p	− 4	+ 8	+14	+ 8	− 3	−15p	− 2	− 7	− 1
2	+18	+11	− 4p	+14	+23	+12	− 6	− 8	± 0	− 4	± 0	+ 5
3	+ 1	+18	+ 4	+16	+11	+31	−17	− 7	−19p	−18	+ 1	−84P
4	± 0p	+28	+ 2	+24	+ 4	− 2	−20	− 6	−24	−12p	−17	+11p
5	−19p	+ 8	+11	+ 7	−12P	−26	− 6	− 6	−30	− 6	−11	− 8
6	−18p	+ 7	+ 7	− 4p	+ 6p	+ 2	+ 2	−35P	− 5p	− 4	−10	+ 2
7	+ 5	+ 6	......	+ 8	+ 8	− 9p	+20	− 1P	−14	−11	± 0	−20
8	+ 7	−11	+14	+ 5p	± 0	− 8	−24	− 3P	+ 4	−10	± 0	− 6
9	+13	+19	+ 4	+ 6	+ 2p	± 0	+32P	−18	−12	− 2	± 0	−29
10	± 0	+ 7	+10	+ 6p	− 1	− 5	+10	−18	−26	−15	−12	− 6
11	+15	− 1	− 3	− 6p	+ 5	−14	+13	− 2	− 5	− 1	−11	− 6
12	+ 6	− 5p	− 9P	+ 6	− 4	−10p	+ 5	− 7p	− 2	− 8	− 3	− 6
13	− 5	−11P	−10P	+11	−24	−10	−28p	− 6	+11	− 5	+ 1	−12
14	+ 8	+ 1P	−10p	+14	− 5	−16	+ 1	−10p	+ 2	−16p	−18p	−27
15	+12	± 0p	−16p	− 4	− 4	+20	−11	−11	− 3	−10	−11	− 8
16	− 4	+ 6	− 7	+ 3	+ 6p	−34P	− 2p	− 7	+ 7	− 9	± 0	−16
17	+11	+ 2	− 3	− 4	−29P	+12	−18	− 5	−12	......	− 2	− 4
18	+11	+ 8	+ 7	−15	−17	+ 2	± 0	− 4	−66P	−11	− 3	− 5
19	......	+ 6	− 9	+ 8	− 3	− 4	− 5	−27	− 8p	−16	+ 5	−23
20	+28	± 0	± 0	−14p	− 8	+15	+ 6	−22	− 9	−19	− 4	− 8p
21	+25	−11	+ 5	−11	− 9	+ 8	−10	+ 2	−11	−18	−11	−14
22	+13	−12	− 1	± 0p	+ 8	+ 9	−10	−11	− 2	−16	− 5	− 9
23	+ 6	−15	+11	± 0	+18	+ 8	+10	− 5	− 4	− 5	−11	−11
24	+ 2	+ 3	− 4p	+ 5	+12	− 8	−19	−10	−10	− 3	± 0	−17
25	+16	−11p	−14	+ 6	− 4	+ 3	− 4p	− 8	− 7	+ 4	−14P	−21
26	− 6	± 0	− 1	− 4	−15	− 9	+ 1	+15	−13	−32P	+ 9	−20
27	± 0	− 2	− 1	− 7	+ 2	+10	−13	− 9	− 2	−12	− 1	− 6
28	+ 5	− 2p	− 1	−12	−14	− 8p	+ 9	+ 3	+ 1	− 4	+ 4	− 7
29	+15		+ 5	− 8	± 0	+11	+15	± 0	−14P	−13p	+ 4	+10
30	− 8		+ 2	+20	− 2p	+17	+10	−19	−23p	−18p	+ 5	−12
31	+15		+ 8		+14P		+ 3	−12		− 7		−15

In forming eighth-values for P, *sums* were used instead of averages, the multiplication by (8/27) being omitted in order to obtain, for P, numerical values of the same magnitude as for R and W. Thus, for the first seven days of rotation No. 1417, C_8 = 0, 1, 3, 5, 7, 7, 4; the eighth-values are given in Table 6.

The present transformations of the observational material serve mainly to clear up the relations between R and W, while P is carried along for

TABLE 5—Continued

Day	1931											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	− 2	−15	−16	− 7	− 2	+ 7*p*	−17	−11	− 3	−19*p*	+ 3	−16
2	− 2	−16	−13	− 3	− 4	−25*p*	− 3	− 2	−18	+10*p*	−21	− 5*p*
3	± 0	−17	− 7	− 2	− 4	−10	− 1	− 3	−14	− 1	−14	− 9*p*
4	± 0	− 3	−20	−10	−14	−19	−10	+10	− 9*p*	− 8*p*	−27	−24*p*
5	− 2	−12	− 8	+ 2	− 2	− 1	−15	+ 8	+ 1	−19*p*	−14*p*	−16
6	+ 2	− 6	− 4	− 2	−18	−15	+ 3	− 5	− 2*p*	− 5	−19*p*	−23
7	+ 2	− 4	− 4	−17	−16*p*	− 2	+ 4	−23	− 5	−11	−10	−13
8	− 4	+ 4	+ 3	− 6	+ 6	+ 5	+ 7	− 9*p*	−11	+11	−26*p*	− 9
9	− 8	− 1	−23	−14	−16	−17	+11	−13*p*	−24	+ 8	−11	− 7
10	− 4	−13	− 8	−10	− 5	−16	+ 6	− 3	−10	+ 1	−13	− 8
11	−16	− 6	−17	−13	−15	−23	+ 3	− 3	−18	− 4	−13	+ 3*p*
12	− 3	−12	+ 2	+ 2	−12	− 5	± 0	−19	−27	−20*p*	−12	−16
13	− 7	−22*p*	− 6*p*	−11	+ 5*p*	−15	− 2	−15	−21	− 9*p*	−15	− 6
14	−21	−17*p*	− 5	+10	−17*p*	−14	+ 4	−12	−25	− 4	−22	− 1
15	−12	−12*p*	+ 4	− 7	−17*p*	− 7	+ 4	− 3	−17*p*	−13	−12*p*	− 6
16	−11*p*	−10	+ 2	+ 2	−17	−24	+ 4	−11	−21	−18	−14*p*	− 2
17	+ 2*p*	− 7	+ 5	− 6	± 0	−13	− 6	−22	+ 2	−19	− 7	−22
18	−12*p*	− 5	− 2	−19	−17	−22	− 8	−10	+ 3	−15*p*	−18*p*	−20
19	− 9	−14	− 2	− 1*p*	−12	−22	− 9	− 9	+ 1	−16	− 6	−18
20	−16	+11	+ 2	−17	− 8	−29	−14	−24*p*	− 1	−17	−10	− 9
21	− 1	−13	−11	+ 1	−12	− 4	+ 2	−39*p*	−12	−12	− 4	−10
22	− 5	+ 1	− 7	−12	−18	−27	+ 5	−26	− 9	−11	−14	− 8
23	+ 7	−12	−12	−11	−25	−22	−10*p*	− 7	−19	−22	−10	−17
24	− 2	−40*P*	− 9	−13	−23	−19	+ 1	−13	− 4	−12	−10	− 7
25	+ 1*p*	−17*p*	− 2	− 2	− 6	−16	−24*p*	−11*p*	− 3	−11	− 9	± 0
26	−16	−19*p*	−21	−10	−10	− 1*p*	−11	−13	−10	+ 3	−43*p*	− 2
27	− 5	−10	− 6	− 5	− 7	−20*p*	+ 5	− 8	− 5	−14	......	−17
28	−12	−14	−13	− 5	−12	−12*p*	−24*p*	−19	+ 4	−12*p*	−12	− 7
29	−22		−12	+ 2	− 4	+ 1	−23	−26	−10	−77*P*	− 4	−22
30	−21		−12	− 8	−25	−12	− 8	− 7	−32	−24*P*	− 2	− 2
31	−13		− 3		− 3		+13	−10		−16		− 3

comparison only. The study of P itself—for which the much longer series since 1884 is available—will require more specific statistical methods (to be covered in Part II of this paper).

§ 10. *Eighth-deviations*

For the study of the short-period variations, the observational material can be expressed still more advantageously by calculating running averages

Table 5—Continued

Day	1932											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	± 0	− 7	−13	− 4	+11	−17	−11	−15	−31	−10	−14p	−18
2	−13	−19	−15p	− 7	+ 2	−16	−12	−14p	−14	− 8	−18	− 7
3	−16	−14p	−24p	− 6	+10	−14	− 7	−31p	− 4	−12	−28	− 8
4	−12	−15p	−14p	−20	− 5	−23	+11	−28	− 8	+ 1	−27	− 8
5	−12	−16	−13	− 8p	−15	+11	− 1	+ 1	− 2	−10	−13	−18
6	−12	−11	−17	−10	−10	− 5	−30p	−21	−61p	−16	− 5	−21
7	− 4	−20	−14	−24	−10	− 6	−23	−15	−14	−19	−10	− 6
8	− 7	−15	−14	−12	− 2	+ 2	− 1	− 3	− 1p	−22	−22	−11p
9	−15	− 9	−19	−16	− 5	+10	−13	− 2	− 8	− 9	−17	−18
10	−14	−15p	−18	− 6	−12	+ 2	−15	− 9	−12	−15	−22	−15
11	−11	− 9	−18	− 6	−20	−20	−18	−10	−27	−10	− 6	−18
12	−22	......	−20	− 7	−15	− 8	− 8	− 7	−17	−11	−11	−12
13	−12	−15	−15	−17	− 4	−27	− 6	−12	−22	−16	−18	− 2
14	−22	− 8	− 9	−23	−14	+12	−13	− 7	−14	−11	−30p	−41P
15	− 4	−14	+ 2	......	− 8	− 9	−15	−15	− 5	−34P	−13	−10
16	−17	− 4	− 1	−12	−12	− 3	−40p	−16	−12	− 9	−17	−12
17	− 9	−19	+ 1	−14	−11	− 2	−21	−21	−27	− 5	−13	−21
18	−24	−12	−17p	−29	−10	−16	−15	−14	− 8	− 5	− 1	−18
19	+ 5	+ 4	−10	−18	− 1	+ 1	−16	−24	− 2	−18	−16	−14
20	−14	−24p	−14	−11	+ 4	−30	−17	−13	− 7	−30p	−18	......
21	−30	−23	−23	− 3	−17	− 1	−21	−32	− 5	− 6	−20	......
22	−21	−21	−13	− 7	−24	− 6	+ 3	−22	− 5	−11	−16	......
23	−20	− 4	− 3	−13	−23	−17	− 2	−21	−24p	−21p	−13	−12
24	−16	−16	− 2	− 8p	− 8	− 6	−10	−28	−24p	−12	−43	−12
25	......	− 4	− 6	−17	± 0	+ 4	−13	−10	−23p	−24	−16	−26
26	−10p	− 3	− 9	−22	+ 1	+ 3	+ 4	−34	−10	−13	−31	−18
27	−25p	− 4	+ 5	− 5	+ 1	−19	+ 3	−25p	−14	−13	−20	−20
28	− 8	−15	−18p	−22	− 1	−11	+ 2	−20P	−17	−17	− 6	−24
29	+ 1	−14	+ 1p	−29	−38P	−25	−11	−22p	− 4	−23	−16	−14
30	− 2		−20p	−18	− 3p	− 7	− 7	−16	− 4	−24	−16	−20
31	−14		−15		−10		− 6	−22		−13		− 4

for 27 days and subtracting these from the eighth-values. The *eighth-deviations* thus formed will be designated ΔR, ΔW and ΔP (Table 7). For instance, the average for the 27 days centered at the eighth 1420*a* is, with sufficient accuracy, obtained by adding the eighth-values for 1419*f*, *g*, *h*, 1420*a*, *b*, *c*, *d*, and half the eighth-values 1419*e* and 1420*e*, and dividing this sum by 8; thus, from Table 6, the average is 24, and ΔR becomes (27-24) = 3.

TABLE 5—Continued

Day	1933											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	−2	+3	−4	−15	−69*P*	−22	−26	−24	−12	−3	−18	−13
2	−13	−18	−2	−10	−10	−12	−29	−12	+4	−18	−1	±0
3	−18	−4	−5	−16	−2	−16	−16	−2	±0	−11	±0	−7
4	−4	−3	−14	−12	−11	−3	−20	−20	−13	−2	−13	−30*p*
5	−20	−3	−6	−19	−2	−22	−21	−22*p*	−23	−3	−18	−25*p*
6	......	−5	−24	−13	−17	−4	−22	+1	−5	−9	−30	−16
7	−14	−9	−6	−19	−10	−17	−4	−33	−27	−18	−24	−13
8	−11	+10	−6	−17	−20	−13	−4	−14	−15	−5	−16*p*	−10
9	−3	−10	−5	−12	−14	−15	−34	−21	−13*P*	−10	−14	−25
10	−7	−11	−4	−17	−4	−11	−16	−13	−11	−11	−19	−20*p*
11	−20	−2	−30	−12	−19	−22	−5	−20	−13	−11	−12	−10
12	−5	−11	−25	−10	−5	−15	−20	−21	−18	−16	−8	−5
13	−19	+3	−24	−11	−11	−11*p*	−10	−19*p*	−31*P*	−2	−16	−2
14	−16	−12	−20	−15	−12	−5	−18	−24	−21	−14	−31	−14
15	−26	−5	−11	−23	−18	−13	−11	−14	−11	−14	−13	−10
16	−15	−13	−14	−26	−10	−6	−8	−2	−8	−6	−16	−8
17	−26	−13	−22	−36	−14	−15	−8	−10	−22	−15	−20	−11
18	−14	−7	−8*p*	−26	−8	−11	−3	−17	−12	−17	−17	−14
19	−30	−38*P*	−16*p*	−22	−6	−33	−17	−7	−23	−12	−5	−23
20	−6	−4	−18*p*	−26	−11	−1*p*	−9	−26	−8	−15	−1	−5
21	−10	−20*p*	−16	−7	−20	−17	−9	−18	−9	−21	−14	−18
22	±0*p*	−4	−25	−5	−14	−6	−20	−5	−9	−6	−6	−10
23	−15	−20*p*	−20	−27	−18	−4	−29*p*	−21	−7	±0	−13	−14
24	−14	−27*p*	−28	−8	−7	−6	−29*p*	−17	−12	−2	−23	−18
25	−18	+3	−11	−18	−7	+6	−7	−25	−18	−34	−11	−6
26	−10	±0	−12	−21	−8	−25	−7	−11	−8	−24	−25	−9
27	−2	−11	−25	−24	−8	+1	−18	−17	−8	−19	−11	−3
28	−11	−4	−25	−12	−17	−19	−17	−15	−9	−16	−6	−11
29	−11		−20	−13	−40	−25	−26	−4	−3	−10	−34	−11
30	±0		−9	+6	−4*p*	−34	−31	−16	−7	−3	−2	−1
31	−5		−7		−10*p*		−31	−12		−10		−9

§ 11. *Decade-deviations*

For demonstrating the relations between R and W in individual cases, the remaining uncertainties in the determination of W were still further reduced by forming running averages $\Delta_3 W$ over three consecutive eighth-deviations, to be ascribed to the eighth in the middle. For instance, from Table 7, $\Delta_3 W$ for 1420*a* will be $(+13 + 7 + 2)/3 = +7$. Since three-

Table 5—Continued

Day	1934											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	− 9p	−27	−18	−14p	+ 7	− 6	−25	−16	− 5	− 3	− 8	− 7
2	− 6p	−22	−23	−14	− 5p	− 9	−22	−10	−37p	− 9	−10	− 3
3	−12	− 6	−23	− 2	− 6	+ 9	−18p	−18p	− 6	− 4	−13	− 2
4	− 6	− 9	−14p	− 2	−12	− 5	−23	−10	−12	−13	−14	−14p
5	− 7	− 6	−23p	−21p	− 7	−16p	−18	−13	− 2	−17	−17	−19
6	−19	−16	−15	−20	+ 1	− 1	− 2	−24	+ 3	− 1	−15	−15
7	+ 4	−15	−17p	−13	− 1	−22	− 5	− 2	− 6	− 7	−28p	− 9
8	−14	− 6	− 9	− 9	−15	− 4	− 7	− 9	− 5	− 3	− 8p	− 6
9	− 6	−38P	−13	− 3	−15	−10	± 0	− 3	− 9	−15	− 6	− 8
10	−10	−23p	−19	+ 3	−12	−11	− 9	−10	−19	−10	−16	− 8
11	−15	−16	−16	± 0	− 6	−11	+ 2	− 7	−17	− 3	−14	+ 6
12	−19	−18	−16	− 9	+ 1	+16	−19	− 1	−16	−15	−19	−19
13	−28	− 7	−10	−11	−11	−30	−11	−19	− 7	−14	−27	− 8
14	−19	−17	− 5	+ 2	−20	+13	+ 2	−18	− 7	− 8	− 8	−16
15	−23	− 3	−10	− 6	− 7	−18	−12	− 6	− 9	−24	−12	−13
16	+ 2	−54P	− 1	− 8	−16	− 5	− 9	− 9	−18	−17	− 9	−15
17	−10	− 7p	−12	−15	−10	−15	− 9	− 5	−14	−16	− 8	−18
18	−11	− 6	− 8	− 8	−62P	± 0	+ 2	+ 5	−16	−13	− 9	−11
19	−13	−16	−16	−18	− 7	− 4	−20	−28	−10	− 4	−12	− 3
20	−10	−20	−13	−21	+ 5	−11	+ 3	−18	−20	− 1	−10	− 5
21	−15	−13	−16	−13	+10	− 4	−13	−21	−10	− 6	−11	− 4
22	+ 6	−19	−13	−13	−14	− 6	− 7	−38	−19	−18	−13	− 4
23	−27	−12	−12	−11	− 3	− 2	−17	14	−16	− 7	+ 3	+ 4
24	− 9	−20	− 4	± 0	− 6	−22	−14	+ 5	−18p	−16p	+ 1p	− 5
25	−13	−18	−14p	− 8	− 2	+12	−10	− 5	−31P	−13p	−19	+ 1
26	− 3	−16	−12	−19	−13	− 9	−24	−10	− 5	−11p	− 4	+ 9
27	−18	−13	−15	−16	− 1	−20	+ 6	−18p	−16p	−20	+11	− 7
28	−16	−10	+ 1	−22	+ 3	−18	+ 7	−35	−15	−20	+11	− 5
29	−23		−18	+ 1	+ 5	−14	−14	−24	−11	−13	+11	+ 6P
30	− 8		−10	+ 3	− 8	−22	−34P	−25	−13	−16	− 5	−16p
31	− 8		−26p		−17		−16	−21		−10		− 2

eighths comprise 3 times (27/8) = (81/8), or practically ten days, these values will be referred to as *decade-deviations* $\Delta_3 R$, $\Delta_3 W$, and $\Delta_3 P$.

§ 12. *Smoothed decade-deviations*

A final reduction bears on the 27-day recurrence-tendency, in order to study such relations between R, W, and P that persist through several rotations. Table 8 was smoothed "vertically" by overlapping averages

TABLE 5—Continued

Day	1935											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+ 2	−31*p*	−11	−11	−22*P*	−10	+ 7	− 2	−12	− 3	− 2	+17*p*
2	−16	−24*p*	−24	− 5	− 2	−16	−17	− 4	− 6	+ 2	− 4	+ 9
3	− 3	−16	−13	− 7	− 2	− 1	−34	−15	−15	+ 6	−17	+11
4	−10	−10	−20	+ 4	− 5	−19	−27	+11	+ 9	− 3	− 8	+20
5	− 2	− 5	−15	−10	− 4	− 9	−18	− 1	+ 6	− 3	− 9*p*	+15
6	− 6	−12	−18	− 9	+ 2	− 6	+11	−13	+ 9	− 5	− 3	+10
7	−20	± 0	−12	−11	− 8	− 6*P*	− 2	± 0	− 2	−13	− 1	− 4
8	−20	+ 1	−21	−10	−16	+ 7*p*	−15	− 1	± 0	± 0	−13	− 3
9	− 7	− 8	−27	− 4	− 4	−31*p*	−22	+ 8	− 5	−19	+ 2	−17
10	−23	− 3	−22	−30*p*	−12*p*	−34*p*	+ 1	− 2	− 9	−17	− 4	+10
11	−20	−14	−28	−26*P*	− 7	+ 3*p*	−15	−23	−18*P*	−19*p*	+ 3	− 7
12	−12	− 9	− 4	−23*p*	− 6	−15	+ 4	−12	± 0	− 8	− 1*p*	+14
13	−10	−10*p*	−27*p*	−11*p*	+ 5	− 7	− 7	−14	− 6	± 0	+10*p*	+ 7
14	− 8	− 5*p*	−32*P*	− 4	+ 1	−10	+ 8	− 9	+ 1	+ 1	+ 5*p*	+18*p*
15	− 4	+ 1	−19*p*	− 8	+ 6	−12	−11	+ 2	−29	− 1	+ 1	+ 9
16	− 8	+ 9	−18*p*	−14	− 3	−16	− 1	+ 4	−12	−11	− 5	+ 2
17	−17*p*	+ 3	−13	−14	− 1	± 0	− 2	+14	−12	± 0	± 0	+ 4
18	+ 1	+ 4	−14	− 4	± 0	−34*p*	+ 8	+20	−18*p*	+ 3	+14	− 1
19	−11	−24	−10	−15	− 3	−10*p*	+10	− 1	± 0	− 3	+14	− 4
20	+ 3	+ 1	−11	−11	− 7	−13	+23	+15	− 4	−28*P*	+ 8	+ 6
21	− 3	−19	−11*p*	− 5	− 3	−22	+21	−12	−11	− 5*p*	+ 7	+ 5
22	− 9	−10	− 7	−10	−15	− 2	+12	− 6	− 6	− 7	± 0	− 2
23	− 6*p*	± 0	+ 1	−11	− 4	− 4	+13	− 9	−36*P*	+ 3	+ 5	−10
24	−16*p*	−21	−14	− 8	−15	− 6	− 5*p*	− 2	− 6*p*	−49*P*	+ 6	− 4
25	− 6	− 2	−18	−21	− 5	− 1	−14*p*	− 4	−12*p*	± 0	+ 6	+ 5
26	−13	−21*p*	−12	−30	− 8	+ 7	−13	− 2	+ 6*p*	+ 1	+ 7	−18*p*
27	+14*p*	−13	− 6	−12	− 4	− 3	− 3	−11*p*	− 3	−21*p*	+12*p*	+11
28	+15*p*	−12	− 8	−15	− 2	− 6	+ 4	−18	± 0	−11*p*	− 4	+ 7
29	− 8		+ 3	−11	+ 6	+ 8	−13	+ 2	− 1	− 7	− 5	+13
30	......		− 6*p*	+ 3	−16	− 7	−10	+ 6	− 6	−28	+ 6*p*	+14
31	− 9		−15				− 8	− 6		− 3		+35

over three rotations, to obtain "smoothed decade-deviations" $\Delta_3^3 R$, $\Delta_3^3 W$, and $\Delta_3^3 P$ (Table 9); for instance, $\Delta_3^3 R$ for 1420*a* is the average of the values $\Delta_3 R$ for 1419*a*, 1420*a*, and 1421*a*.

§ 13. *Scales*

For clearness, the meaning of the various numerical quantities expressing R, W, and P shall be summarized:

Table 5—Continued

Day	1936											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+40	+ 8	+11	− 6	+ 6	+ 8*p*	+35	+13	+ 3	+20	+18	+17
2	+18	+15	− 7	+13	+14	+26*p*	−66*P*	+10	+11	+11	+33	+18
3	+26	+ 4	+ 4	+ 5*p*	+ 8	+20	+11	−10	+26	+10	+16*p*	+20
4	−12	+ 9	+ 8	− 2	−11	+ 6	+17	+ 1	+25	+19	+ 6	+16
5	− 7	− 6	− 2	+ 5	− 8	− 5	− 4	− 4	+15	+17	+15	+24
6	−16	+13	+ 8	+22	+ 2	+ 9	−21	+ 4	+ 5	+27	+14	+ 8
7	− 6	− 3	− 8	+ 4	+18	+ 1	+ 9	−13	+12	+20	− 5	+ 7
8	−34	+ 4	− 1	− 3	+15	+12	−15	− 1	+16	+13	+14	+15
9	+ 6	+11	− 1	− 6	+14	− 1*p*	− 3	− 4	± 0	+ 8	−12	+22
10	− 2*p*	+11*p*	− 8	− 3	+18*p*	+ 1*p*	−11*p*	− 9	− 8	+10	+22	− 4
11	+ 7	+ 3	+10	− 6	+ 4	+13	± 0	−16	−13*p*	+ 7	+ 2*p*	+ 6
12	+ 1	+ 6	+ 5	+14	+12	−10	+ 2	− 3	+ 6	+ 8	+23	+ 4
13	− 5*p*	− 2	+24	+ 7	+ 5	+25	+ 7	+ 2	+30	+ 9	+27	± 0
14	+ 9	+ 6	+ 2	+15	+17	+ 7	+20	+ 6	+12	+ 1	+19	+ 4
15	− 8	+12	− 3	+ 4*p*	+ 6	+14	+10	+ 8	− 4	+14	−20	+ 1
16	−16	+ 8*p*	+ 2	− 1	−11*p*	+12	+19	+ 8	+15	+10*P*	+ 5	−11
17	+ 8	− 1*p*	+15	+ 6	+ 5	− 3	− 2	− 4	+ 2	+ 8*p*	+15	− 4
18	− 9*p*	+ 8	+19	+14*p*	+ 7*p*	+12	+10	−12	+ 3	+18	+17	− 1
19	+ 1	+13*p*	+18	+ 4*p*	+15	− 2*P*	− 6	+ 7	+16	+13	+24	+24
20	+ 3	+10	−12	+ 6	+ 5	+13	− 1	− 8	+18	+11	± 0	+12
21	+ 6	± 0*p*	−18	+ 2*p*	+16	+20	+ 8	+18	+ 9	+ 7	+10	+20
22	+ 9	+ 6	−10	+ 9*p*	+ 4	+ 9	−24	+15	+12	+14	+ 8	+20
23	+17	+ 7	+ 2*p*	− 6	+ 3	+19	+ 4	− 6	+ 4	+20	+ 9	+16
24	+ 9*p*	+12	− 4*p*	+ 2	+21	+17	−16	± 0	+ 3	± 0*p*	+13	+ 4
25	+ 8*p*	+17	+ 9	− 5	+22	+12	+ 2	+19	+20	+11	+21	+18
26	+ 9	− 6	+14	+11	− 2	+25	+ 3	− 9	−18	+21	+ 9	+21
27	+10	−10	− 2	± 0	+ 7	−11	− 5	+ 1	+ 8	+11	+10	+22*p*
28	± 0	+ 4	− 2	− 9	+ 3	+13	− 5	+ 8	+29	+16	+21	− 1*p*
29	+13	+ 5	± 0	+ 6	− 6*p*	+12	−32*P*	+10	+21	+18	+23*p*	+21
30	+ 1		+10	± 0	+16	+ 1	+ 7	+10*p*	+20	+ 5	+32	+55
31	+16		+ 8		+ 7		+10	− 2		−12*p*		+35

Sunspots—From the eighth-values for R, approximate values in the ordinary units of the daily Zürich sunspot-numbers R can be obtained by multiplication with 5, followed by subtraction of 2 units, except that the eighth-value 0 corresponds exactly to $R = 0$. Eighth-deviations ΔR, decade-deviations $\Delta_3 R$, and smoothed decade-deviations $\Delta_3^3 R$ need only multiplication by 5 to show the variations of solar activity in units of R.

Wave-radiation—The annual variation of $\omega_2 = 0.4\omega_1$, and of $A_{S;R=50}$

TABLE 5—Concluded

Day	1937											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	+37	+38	+ 9*p*	+22	+19	+17	+ 1	− 4	+ 6	+24*p*	+ 9	+26
2	+31	+35	+16	+27*p*	+ 4	+18	± 0	+ 1*P*	+20	+38	+30	+20
3	+22	+48*P*	+13	+18	− 6	+ 3	+15	+23	+38	+ 9*p*	+18	+18
4	+13	+54*p*	+20	+ 5	−14*p*	+20	+16	+15	+16	+51*P*	+13	+12
5	+23	+41*p*	− 2*P*	+ 8	−14*P*	− 8	+27	+35	+23	+39	+17	+ 1
6	+21	+28	+22	+24	+22	− 8*p*	−23*p*	+11	+27	+44	+10	− 1
7	+28*p*	+ 6	+18	+ 7	+ 8	+ 1	+24	+41	+38	+16	+16	− 1
8	+16	− 7	+15	+16	+10	+25	+26	+29	+28	+19*p*	− 2	− 6
9	+28	+ 6*p*	+20	+ 1	− 9	+10	+44	+34	± 0	−15*P*	+17	+14
10	+17	− 2*p*	+18	+ 3	+ 3	+17	+28	+40	+22*p*	+20*p*	+11	+11
11	+18	+21	+16	+10	+ 2	+23	+12	+27	− 1	+ 4*P*	+12	+11
12	+20	+11	+ 6	−12*p*	+21	+19	+ 2	+43	+23	+21*p*	+ 3	+14
13	+20	+16	+ 8	+ 8	+20	± 0*p*	+29	+56	+20	+13	+19	+14
14	+15	+21	+13*p*	+ 7	+24	+42	−28*p*	+52	+15	+18	− 3	+24
15	+ 4	+ 6	−13*p*	+10	+21	+21	+17	+25	+12	− 8*p*	+10	− 4
16	+16	+26	+ 4	+ 9	+15	+34	+30	+17	± 0	± 0	+ 2	+20
17	+ 9	+27	± 0	+ 4	+22	+49	+25	+20	+ 9	+16	+ 8	+ 9
18	+ 4	+28	+14	− 4	+32	+34	+ 5	+22	+ 8	+11	+ 8*p*	−19*p*
19	+14	+20*p*	+25	+11	+16	+28	+51*p*	+24	+17	+ 8	± 0*p*	+ 6*p*
20	+19	+16	+ 3	+ 3	+12	+22*p*	+18	+22	+21	+ 7	+27*p*	+26*p*
21	+23	+24	+21	+11	+27	+37	+30	+31	+14	−12	+34	+26
22	+22	+15	− 2*p*	+19	+25	+33*p*	− 5*p*	− 1*P*	± 0	+12	+16*p*	+18
23	+23	+31	+21	+17	+19	+42	+26*p*	+ 8	+ 6	± 0*p*	+20*p*	± 0*P*
24	+ 6	+43	+25	+40*P*	+25	+19	+20	+ 1	+11	− 2*p*	+28	+27*p*
25	+33	+39	+25	+51*P*	+40*p*	+30	+16	+34	+21	+13	+38	+20
26	+22	+36	+19	+44*P*	+ 4	+14	+16	+34	+18	± 0*p*	+24	+26
27	+13*p*	+32	−12*P*	+15*p*	+21	+17*p*	− 4	± 0	+ 9	− 2*p*	+17	+20
28	+ 6	+ 9	+12*p*	−24*P*	− 6*P*	+21	+22	+32	+15	+16	+14	+23
29	+31		+ 4	+12*p*	+10	+ 7	+12	+22	+19	− 4	+ 5*p*	+20
30	+42		+24	− 3	+20	+39	+24	−15	+48*P*	+18	+ 4*p*	+10
31	+35		+11*P*		+20		+22	+12		+13		− 4

shown in Table 2, produces a similar annual change in the meaning of δW_2 and the derived eighth-values, etc., exactly expressed by Table 2. For a rough approximation, one may put $A_{S;R=50} = 100\gamma$, and $\omega_2 = 0.5$, that is, $\delta W_2 = 0.5\ A_S - 50$; a change of δW_2, ΔW, $\Delta_3 W$, or $\Delta_3^3 W$ by one unit corresponds then to a change of A_S by 2γ, or two per cent of $A_{S;R=50}$.

Particle-radiation—The relation between C_8 and C_{int} (§ 8) is not uniform for the higher values of C_{int}, but since these are less frequent than the

TABLE 6—*Averages of $(R/5)$, δW_2, and C_8 for eighths of rotations*

Rotation		Sunspots R									Wave-radiation W									Particle-radiation P								
No.	First day	Av. $(R/5)$ for eighth								Sum	Av. δW_2 for eighth								Sum	Sums C_8 for eighth								Sum
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*		*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*		*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	
	1922																											
1218	Jan. 26	0	0	1	5	7	12	4	3	32	....	....	....	....	....	....	....	....	.....	7	11	15	11	12	17	16	10	99
1219	Feb. 22	3	11	24	23	16	17	6	3	103	....	....	....	....	....	....	....	....	.....	2	12	18	11	5	20	13	15	96
1220	Mar. 21	1	7	7	6	5	1	0	0	27	−18	−5	....	....	....	....	−6	−11	.....	5	9	14	13	1	13	16	12	83
1221	Apr. 17	0	1	4	4	7	4	2	0	22	−7	−19	−8	−16	−1	−15	−19	−4	−89	5	16	20	12	3	9	19	8	92
1222	May 14	0	0	0	2	2	2	0	2	8	−5	−7	−5	−18	−8	−3	−8	−7	−61	8	7	15	13	4	8	15	6	76
1223	June 10	3	4	1	1	1	0	0	2	12	−12	−6	−1	−9	−9	−16	−7	−14	−74	5	8	14	7	4	15	17	7	77
1224	July 7	5	2	0	2	6	4	1	0	20	−10	−6	−21	−17	−10	−23	−6	−10	−103	4	2	16	13	3	13	19	9	79
1225	Aug. 3	2	1	0	0	0	0	4	4	11	−5	−10	−9	−21	−16	−20	−12	−18	−111	8	6	21	16	2	13	13	11	90
1226	Aug. 30	2	0	0	0	2	2	2	1	9	−18	−19	−25	−19	−6	−12	−9	−1	−109	10	6	17	14	17	8	13	2	87
1227	Sep. 26	1	2	1	0	3	1	3	2	13	−8	−12	−3	−9	−11	−9	−11	−12	−75	11	9	20	18	8	7	5	7	85
1228	Oct. 23	0	0	2	2	2	3	3	1	13	−16	−10	−14	−6	−9	−10	−9	−12	−86	9	7	19	14	2	8	3	4	66
1229	Nov. 19	2	0	0	3	5	4	2	0	16	−13	−11	−11	−11	−13	−11	−6	−9	−85	6	2	11	14	5	6	11	11	66
1230	Dec. 16	0	1	4	9	8	4	0	0	26	−6	−9	−19	−19	−14	−8	−17	−15	−107	0	0	7	8	6	6	3	4	34
	1923																											
1231	Jan. 12	0	0	1	1	1	2	0	1	6	−9	−21	−11	−2	−1	−11	−13	−7	−75	10	4	11	12	2	13	10	9	71
1232	Feb. 8	0	1	1	0	0	0	0	0	2	−11	−11	−9	−9	−1	−13	−12	−9	−75	8	4	9	7	0	23	7	1	59
1233	Mar. 7	0	0	1	0	2	2	1	3	9	−15	−10	−7	−13	−11	−10	−2	+2	−66	3	2	13	10	5	23	11	3	70
1234	Apr. 3	0	0	0	1	2	3	2	3	11	−3	−7	−3	−2	0	−12	0	−20	−47	1	6	14	9	1	18	8	1	58
1235	Apr. 30	0	0	0	1	1	0	1	2	5	−7	−17	−7	−7	−7	−14	−11	−19	−89	3	10	7	1	4	18	5	2	50
1236	May 27	1	3	1	0	0	0	1	2	8	−27	−13	−14	−23	−21	−12	−3	−8	−121	9	6	11	4	5	17	2	10	64
1237	June 23	4	5	5	1	0	0	0	0	15	−14	−4	−26	−6	−3	−7	−5	−14	−79	1	8	12	3	9	13	2	8	56
1238	July 20	1	2	1	1	0	0	0	0	5	−7	−5	+1	−15	−1	−2	−16	−8	−53	6	3	5	0	11	6	3	11	45
1239	Aug. 16	0	1	0	0	1	4	4	4	14	−10	−11	−8	−10	−13	−9	−22	−3	−86	1	3	6	1	5	6	0	9	31
1240	Sep. 12	2	3	1	1	4	3	2	0	16	−6	−4	−17	−7	−10	0	−9	−6	−59	6	5	3	3	21	10	1	4	53
1241	Oct. 9	2	2	2	2	6	5	4	6	29	−13	−1	−11	−2	−7	−14	−2	−15	−65	10	12	23	8	2	7	6	12	80
1242	Nov. 5	4	2	2	1	0	1	2	1	13	−6	−14	−4	−19	−14	−14	−21	−8	−100	4	0	8	2	3	6	7	13	43
1243	Dec. 2	0	0	0	0	0	3	3	1	7	−16	−20	−18	−12	−11	−11	−17	−10	−115	6	3	10	9	3	4	13	18	66
1244	Dec. 29	0	1	1	0	0	0	0	0	2	−3	−5	−7	−14	−22	−4	−14	−9	−78	4	8	5	14	3	10	4	18	66
	1924																											
1245	Jan. 25	0	0	0	0	0	0	1	0	1	−9	−10	−7	−8	−5	−8	−12	−25	−84	9	18	5	15	7	4	6	9	73
1246	Feb. 21	0	5	4	2	0	0	0	0	11	−17	−16	−10	−10	−17	−15	−12	−12	−109	19	11	0	13	15	12	1	4	75
1247	Mar. 19	0	1	0	0	0	1	0	1	3	−13	−13	−14	−7	−12	−13	−13	−8	−93	16	9	3	16	3	10	2	2	61
1248	Apr. 15	1	8	7	3	0	0	2	4	25	−8	−4	+5	−25	−14	−5	−12	−7	−70	7	8	7	14	5	2	2	3	48
1249	May 12	8	9	6	5	4	4	9	10	55	−10	−4	−14	−10	−9	−4	−5	+1	−55	6	6	11	21	12	7	2	1	66
1250	June 8	5	4	5	4	3	4	4	7	36	−4	−2	−12	−3	−10	−13	−13	−5	−62	16	12	10	21	12	5	7	2	85
1251	July 5	8	11	10	5	2	4	4	4	48	+1	−6	−1	−13	−18	−16	−19	−10	−82	7	14	5	12	14	4	17	2	75
1252	Aug. 1	6	5	3	3	3	3	3	3	29	−7	−7	−11	−9	−12	+4	−14	−7	−63	8	12	3	1	6	9	2	1	42
1253	Aug. 28	8	9	7	4	5	4	3	5	45	−14	−8	−6	−11	−8	−14	−4	−4	−69	13	9	15	19	11	4	5	8	84
1254	Sep. 24	5	7	8	8	8	5	4	4	49	+1	−3	−6	−6	−5	−2	+1	−12	−32	13	10	1	10	6	0	8	8	56
1255	Oct. 21	4	5	4	2	0	0	2	5	22	−7	−11	−7	+1	−12	−4	−12	−4	−56	15	14	4	14	6	6	7	7	73
1256	Nov. 17	8	11	11	4	1	0	3	6	44	−11	−2	+1	−12	−10	−1	−7	+2	−40	7	4	16	8	1	2	7	12	57
1257	Dec. 14	5	5	8	4	1	0	1	0	24	+4	+4	−7	−15	+6	+5	−12	+1	−14	5	11	14	2	1	3	4	2	42

TABLE 6—Continued

Rotation		Sunspots R									Wave-radiation W									Particle-radiation P								
		Av. (R/5) for eighth									Av. δW_2 for eighth									Sums C_8 for eighth								
No.	First day	a	b	c	d	e	f	g	h	Sum	a	b	c	d	e	f	g	h	Sum	a	b	c	d	e	f	g	h	Sum
	1925																											
1258	Jan. 10	2	1	4	4	1	0	1	3	16	+ 6	+ 2	− 3	− 1	−10	−12	−18	−15	− 51	2	8	21	12	7	0	4	0	54
1259	Feb. 6	5	8	11	6	4	2	2	3	41	−12	−12	− 6	−18	−18	− 6	−20	− 7	− 99	11	8	5	9	4	7	6	4	54
1260	Mar. 5	0	1	4	6	6	4	8	6	35	−13	−13	− 2	− 4	−12	− 8	− 7	−12	− 71	6	13	3	8	6	6	6	2	50
1261	Apr. 1	2	4	8	12	8	10	8	6	58	− 6	− 9	− 5	− 2	− 2	+ 5	− 4	− 5	− 28	12	9	14	8	8	5	3	5	64
1262	Apr. 28	3	6	8	8	7	12	15	12	71	− 4	− 5	−10	0	+ 1	−18	− 1	− 4	− 41	4	7	12	5	0	1	7	5	41
1263	May 25	7	6	14	17	22	19	6	2	93	−13	− 3	−12	− 4	+ 3	+ 7	+ 3	− 3	− 22	10	16	15	11	3	12	11	6	84
1264	June 21	2	3	3	7	11	10	9	8	53	− 7	− 6	+ 3	− 3	+ 2	0	+11	−12	− 12	10	17	18	5	4	11	4	7	76
1265	July 18	8	4	7	8	6	3	10	11	57	− 8	−10	− 2	− 8	− 7	−13	−12	− 5	− 65	4	11	19	6	7	11	16	1	75
1266	Aug. 14	4	4	6	11	15	16	14	11	81	+ 3	−23	− 9	−11	−14	+12	+ 8	−10	− 44	4	12	17	6	6	19	11	9	84
1267	Sep. 10	7	8	10	15	16	16	14	10	96	− 4	− 7	+ 1	+13	+10	+15	+ 9	+ 2	+ 39	0	17	9	16	14	0	5	12	73
1268	Oct. 7	8	11	17	24	23	17	8	7	115	− 2	+ 6	+ 9	+10	+10	+11	− 2	+ 6	+ 48	17	18	11	5	23	14	4	15	107
1269	Nov. 3	5	6	9	9	11	18	25	18	101	− 1	− 3	+ 4	− 1	+ 8	+ 1	+ 4	+ 2	+ 14	1	12	16	13	0	1	7	0	50
1270	Nov. 30	14	15	17	18	26	26	24	22	162	+ 6	− 7	− 4	+12	+17	+ 5	+ 9	+ 3	+ 41	4	10	10	7	8	7	4	7	57
1271	Dec. 27	18	18	10	13	17	12	18	19	125	+17	+12	+ 6	+ 1	− 1	+10	+10	+17	+ 72	17	10	9	11	9	20	14	10	100
	1926																											
1272	Jan. 23	21	12	8	9	7	12	28	25	122	+ 7	+11	+ 4	+11	+ 5	+ 2	+11	+15	+ 66	13	18	8	15	1	12	16	16	99
1273	Feb. 19	15	11	11	16	22	17	11	18	121	+ 2	+16	+ 9	+ 1	+ 8	+13	+ 1	+ 9	+ 59	11	23	11	15	19	16	10	8	113
1274	Mar. 18	12	7	9	6	7	6	7	9	63	− 7	− 4	+ 2	− 3	+ 8	+11	+ 3	+ 9	+ 19	18	13	6	14	6	10	16	10	93
1275	Apr. 14	14	14	7	4	6	12	15	19	91	+12	+ 9	+ 5	− 3	−10	− 1	+ 7	+16	+ 35	25	7	15	12	1	6	19	16	101
1276	May 11	17	15	15	11	6	10	12	17	103	+14	+20	+17	+ 7	− 2	+ 1	+ 8	+ 8	+ 73	15	5	13	6	1	1	16	4	61
1277	June 7	19	16	14	11	9	14	21	18	122	+ 7	− 2	− 8	+ 4	+ 8	+ 2	+ 5	+ 1	+ 17	16	4	7	4	6	5	5	5	52
1278	July 4	10	6	4	2	2	11	20	22	77	−11	− 1	+ 1	− 5	− 6	+ 7	+ 5	+ 4	− 6	12	8	5	4	7	1	7	12	56
1279	July 31	17	18	11	13	11	9	13	15	107	+ 1	+ 9	+ 6	+14	+ 7	−10	+ 9	0	+ 36	17	6	4	11	13	14	1	3	69
1280	Aug. 27	11	8	6	8	7	12	20	21	93	+ 4	0	0	+ 6	0	− 6	+10	+ 6	+ 20	2	4	0	17	16	17	16	22	94
1281	Sep. 23	15	16	7	8	16	25	25	15	127	+ 7	+ 1	− 3	− 1	+ 5	+ 8	+ 8	+ 2	+ 27	8	0	1	12	8	7	24	16	76
1282	Oct. 20	8	12	15	11	13	8	8	8	83	− 4	− 7	−14	+ 3	+ 4	+ 3	+ 1	+ 9	− 5	3	10	8	9	8	3	4	1	46
1283	Nov. 16	7	15	22	18	18	14	12	16	122	− 7	+ 4	− 5	+ 8	+ 1	+ 3	− 6	+11	+ 9	3	9	7	12	8	7	2	8	56
1284	Dec. 13	21	19	18	19	14	11	15	20	137	− 3	+14	− 2	+ 6	+ 4	0	+ 6	− 4	+ 21	8	7	10	12	13	12	12	19	93
	1927																											
1285	Jan. 9	24	14	18	16	14	9	23	30	148	+ 4	+12	+ 3	+10	+ 5	− 5	− 2	− 7	+ 20	6	8	7	4	9	9	4	8	55
1286	Feb. 5	30	25	17	15	13	10	13	10	133	+26	+16	+10	+13	− 1	+ 2	+16	+ 7	+ 89	4	16	14	12	7	8	14	11	86
1287	Mar. 4	13	16	12	19	26	22	9	5	122	+17	+ 8	+12	+ 7	+ 4	+16	+ 9	+ 5	+ 78	7	14	12	20	16	2	10	18	99
1288	Apr. 31	13	19	21	27	28	22	13	13	156	+ 9	+12	− 4	+ 7	+17	+15	+ 8	+ 5	+ 69	7	10	14	18	14	0	2	13	78
1289	Apr. 27	12	11	18	19	23	13	17	17	130	+18	− 3	+ 5	+ 5	+14	+11	− 2	+ 8	+ 56	2	9	18	15	2	12	9	8	75
1290	May 24	19	11	7	10	15	13	9	8	92	+ 5	+ 3	+11	+ 8	+12	+ 1	+ 4	− 1	+ 43	4	12	10	11	2	13	7	3	62
1291	June 20	7	14	21	22	20	11	7	7	109	+ 1	− 1	+ 4	+ 8	+ 7	− 8	+ 2	0	+ 13	1	5	7	11	7	9	3	1	44
1292	July 17	8	9	13	10	10	10	6	6	72	− 2	− 5	− 1	+ 3	− 5	+ 3	+ 1	0	− 6	9	20	11	5	9	13	3	3	73
1293	Aug. 13	12	16	12	13	12	13	10	9	97	− 6	0	+15	+ 4	+13	− 9	−10	0	+ 7	7	7	21	3	8	19	12	20	97
1294	Sep. 9	12	22	22	14	16	12	7	13	118	− 6	+15	+ 7	+ 6	+ 5	+10	0	+12	+ 49	19	13	4	6	4	15	10	10	81
1295	Oct. 6	17	20	16	9	12	13	7	11	105	+11	+ 9	+21	+17	+ 1	+ 7	− 7	+ 8	+ 67	20	19	15	3	10	19	7	5	98
1296	Nov. 2	8	7	14	21	17	15	17	13	112	0	− 6	+ 6	+ 3	+ 6	− 2	− 1	− 4	+ 2	2	3	5	3	9	12	2	3	39
1297	Nov. 29	10	6	13	17	9	3	3	10	71	+ 1	+ 2	+ 4	+ 5	+13	− 5	+ 7	+ 3	+ 30	14	6	12	6	19	18	3	2	80
1298	Dec. 26	11	16	17	19	17	13	15	13	121	+ 7	+12	+11	+21	+11	−10	− 4	− 4	+ 44	8	8	6	4	4	0	3	9	42

TABLE 6—Continued

Rotation		Sunspots R									Wave-radiation W									Particle-radiation P								
		Av. $(R/5)$ for eighth								Sum	Av. δW_2 for eighth								Sum	Sums C_8 for eighth								Sum
No.	First day	a	b	c	d	e	f	g	h		a	b	c	d	e	f	g	h		a	b	c	d	e	f	g	h	
	1928																											
1299	Jan. 22	15	25	17	13	8	7	7	14	106	−1	+6	+17	+8	−7	−3	+2	+7	+29	9	14	9	13	7	1	11	9	73
1300	Feb. 18	21	24	24	18	11	18	21	20	157	+7	+5	+10	−4	+12	+2	+11	+10	+53	14	8	13	4	0	1	13	17	70
1301	Mar. 16	25	21	15	13	15	20	26	25	160	+5	+9	+9	+6	+1	+3	+12	+7	+52	8	6	13	3	7	13	14	10	74
1302	Apr. 12	20	14	7	6	12	21	25	26	131	+19	+20	+14	+13	+7	+23	+22	+9	+127	1	9	12	4	2	0	5	11	44
1303	May 9	22	9	3	3	8	14	29	24	112	+14	+12	+8	+4	+4	+10	+25	+16	+93	15	16	16	7	3	17	15	13	102
1304	June 5	20	9	6	12	18	25	30	26	146	+14	+7	+2	+15	+18	+23	+29	+34	+142	16	6	17	5	9	18	7	7	85
1305	July 2	22	13	17	26	27	26	15	13	159	+9	+16	−2	+7	+7	+32	+39	+8	+116	15	17	18	4	5	10	11	11	91
1306	July 29	21	23	15	15	17	14	12	19	136	+10	+10	+13	+21	+8	+6	+8	+17	+93	9	8	19	3	9	3	2	6	59
1307	Aug. 25	22	18	14	12	19	16	11	17	129	+12	+12	+8	+13	−3	+7	+8	+18	+75	18	4	14	11	19	8	5	16	95
1308	Sep. 21	23	30	23	13	9	13	17	17	145	+22	+10	+25	+11	+15	+20	+12	+11	+126	11	16	5	13	14	5	9	14	87
1309	Oct. 18	15	14	9	7	10	12	15	17	99	+23	+8	+8	+2	+11	−8	−3	+7	+48	20	14	19	10	16	9	5	19	112
1310	Nov. 14	14	10	7	4	5	12	20	16	88	+7	+7	−4	−7	+1	+5	+12	+19	+40	17	12	1	9	3	7	15	7	71
1311	Dec. 11	18	18	7	4	3	10	15	12	87	+16	+7	+11	−6	−1	+4	+8	+14	+53	14	5	1	9	10	6	3	16	64
	1929																											
1312	Jan. 7	15	15	19	18	17	14	6	7	111	0	+9	−5	+6	+12	0	+4	+12	+38	14	8	9	0	7	1	5	5	49
1313	Feb. 3	9	18	20	14	9	12	13	12	107	+14	+6	+4	+6	+11	+10	+8	+14	+73	3	16	13	3	21	13	11	22	102
1314	Mar. 2	12	15	19	16	9	4	5	6	86	−7	+3	+14	+6	+6	+9	+8	+11	+50	11	11	15	21	16	16	12	9	111
1315	Mar. 29	8	9	11	14	14	12	12	10	90	+4	+7	+10	−2	+6	+5	+10	+3	+43	6	10	7	6	3	18	4	2	56
1316	Apr. 25	9	10	17	15	14	14	13	7	99	+14	+5	+5	+12	0	+13	−2	−4	+43	8	15	11	5	4	18	12	4	77
1317	May 22	8	12	7	7	13	14	17	15	93	+4	+6	−2	−2	0	+10	+8	+3	+27	10	9	10	6	3	18	8	4	68
1318	June 18	17	20	15	15	15	15	15	17	129	+4	+4	0	0	+16	+16	+5	+2	+47	4	17	6	12	9	15	13	9	85
1319	July 15	17	17	13	11	10	12	10	12	102	−3	+2	+1	+3	+6	+1	+1	+3	+14	20	7	9	3	5	16	6	0	66
1320	Aug. 11	16	24	21	14	9	6	4	8	102	−3	+5	+8	+8	+7	−7	−4	−3	+11	12	18	14	1	4	3	6	2	60
1321	Sep. 7	12	9	7	6	9	4	7	11	65	+8	−2	−3	+5	−1	+5	−4	+10	+18	18	19	18	5	16	10	5	6	97
1322	Oct. 4	12	15	16	11	5	6	8	16	89	+9	+9	+9	+8	+3	−7	−14	−2	+15	11	21	14	14	19	9	6	13	107
1323	Oct. 31	15	18	17	16	17	12	9	15	119	−14	+11	0	+8	+3	+1	+4	+2	+15	20	21	15	2	13	4	8	5	88
1324	Nov. 27	27	26	19	12	23	28	28	26	189	+5	+19	−3	0	+4	+17	+23	+10	+75	12	6	22	14	12	12	7	10	95
1325	Dec. 24	24	17	9	10	13	14	20	22	129	+17	+3	+13	−8	+4	+7	+4	+6	+46	6	5	9	23	15	2	7	12	79
	1930																											
1326	Jan. 20	13	9	10	13	21	21	16	9	112	+20	+5	+5	+7	+17	+2	+5	0	+61	13	4	6	14	14	4	5	25	85
1327	Feb. 16	5	2	4	4	7	10	8	5	45	+5	−5	−8	−4	−3	+7	+7	−5	−6	19	9	15	16	15	0	3	24	101
1328	Mar. 15	9	8	5	6	9	11	12	9	69	−7	0	−1	+3	+4	+10	+8	+6	+23	19	16	15	15	13	9	12	23	122
1329	Apr. 11	11	6	4	6	5	8	10	7	57	+5	+1	−7	−2	0	0	+12	+7	+16	20	15	18	20	13	15	6	23	130
1330	May 8	5	5	7	7	9	10	9	7	59	+1	−9	0	−9	+9	−5	−5	+19	+1	16	12	19	17	12	8	13	21	118
1331	June 4	7	13	9	5	3	2	4	7	50	−9	−5	−11	+5	+5	+7	−2	+7	−3	13	14	14	15	15	5	5	18	99
1332	July 1	7	6	5	5	5	2	4	4	38	−7	−0	−3	−4	−8	−1	−6	−7	−36	14	12	16	21	15	6	6	18	108
1333	July 28	5	4	2	4	5	2	5	7	34	+10	−4	−6	−15	−7	−9	−15	−7	−53	13	7	13	23	19	16	9	17	117
1334	Aug. 24	8	10	10	13	11	8	6	2	68	−2	−5	−10	−22	−7	−10	+3	−7	−60	12	7	16	19	14	9	4	17	98
1335	Sep. 20	2	4	7	6	8	8	11	7	53	−7	−9	−3	−10	−9	−8	−7	−11	−64	10	8	13	19	18	11	3	9	91
1336	Oct. 17	4	3	6	11	10	5	2	3	44	−10	−15	−1	−11	−7	−9	−2	−8	−63	17	10	14	21	15	10	7	2	96
1337	Nov. 13	2	7	13	12	14	9	4	1	62	−8	0	−6	−3	+4	+3	+2	−16	−24	15	5	0	21	13	7	14	3	78
1338	Dec. 10	4	4	9	7	10	5	2	2	43	−7	−16	−11	−11	−18	−3	−8	−1	−75	6	7	5	19	10	5	4	1	57

TABLE 6—Continued

Rotation		Sunspots R									Wave-radiation W									Particle-radiation P								
No.	First day	Av. $(R/5)$ for eighth								Sum	Av. δW_2 for eighth								Sum	Sums C_8 for eighth								Sum
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*		*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*		*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	
	1931																											
1339	Jan. 6	3	3	7	5	5	4	2	0	29	−1	−8	−12	−7	−8	0	−13	−17	−66	2	11	5	19	8	9	13	7	74
1340	Feb. 2	5	5	5	5	9	14	18	13	74	−12	−4	−6	−16	−8	−5	−9	−15	−75	11	4	2	17	10	1	14	14	73
1341	Mar. 1	7	7	7	9	10	9	5	2	56	−13	−8	−9	−6	+2	−1	−10	−10	−55	9	6	12	15	7	6	12	11	78
1342	Mar. 28	3	7	7	9	8	8	5	7	54	−11	−4	−4	−12	−8	0	−10	−8	−57	5	9	5	6	7	1	15	6	54
1343	Apr. 24	6	4	3	3	5	7	7	6	41	−8	−4	−4	−12	−7	−8	−14	−11	−68	6	2	3	12	5	17	15	7	67
1344	May 21	7	7	4	5	7	8	4	1	43	−19	−10	−13	−8	−11	−6	−15	−15	−97	1	9	5	15	7	13	14	4	68
1345	June 17	1	1	0	4	5	4	7	7	29	−20	−20	−13	−10	−8	−6	+7	+1	−69	2	9	10	14	8	6	2	9	60
1346	July 14	3	1	2	1	4	6	6	1	24	+3	−9	−2	−10	−15	0	+4	−14	−43	11	2	8	15	14	5	8	18	81
1347	Aug. 10	1	0	3	1	1	6	6	5	23	−9	−10	−14	−27	−11	−17	−9	−9	−106	10	7	9	14	15	9	7	16	87
1348	Sep. 6	3	5	5	6	3	3	3	3	31	−8	−19	−22	−4	−6	−9	−4	−13	−85	18	9	15	14	15	11	6	18	106
1349	Oct. 3	3	2	1	2	1	2	4	3	18	−9	+1	−7	−10	−17	−14	−11	−11	−78	19	7	11	13	16	15	9	21	111
1350	Oct. 30	3	4	4	1	0	1	6	8	27	−9	−19	−18	−12	−16	−13	−8	−10	−105	16	16	21	11	14	20	8	6	112
1351	Nov. 26	8	5	1	3	7	7	3	2	36	−24	−7	−16	−14	−7	−4	−16	−10	−98	14	12	20	8	16	14	7	1	92
1352	Dec. 23	5	5	3	3	1	1	1	3	22	−7	−12	−4	−13	−8	−14	−15	−15	−88	9	9	19	10	11	19	13	8	98
	1932																											
1353	Jan. 19	2	4	7	4	4	2	1	1	25	−14	−19	−14	−6	−15	−16	−12	−11	−107	0	9	20	11	15	17	17	14	103
1354	Feb. 15	0	0	3	7	7	6	3	1	27	−12	−13	−14	−6	−14	−16	−17	−19	−111	2	12	18	6	5	21	18	17	99
1355	Mar. 13	0	2	2	1	3	2	2	0	12	−7	−7	−16	−4	−5	−12	−11	−15	−77	4	11	18	8	15	23	20	18	117
1356	Apr. 9	0	1	2	2	6	7	3	0	21	−9	−17	−18	−10	−12	−17	−8	−3	−94	8	15	14	3	20	17	8	18	103
1357	May 6	2	2	5	8	7	6	4	2	36	−7	−14	−10	−9	−10	−10	0	−10	−70	6	9	15	6	8	15	16	16	91
1358	June 2	2	6	7	2	4	7	7	7	42	−15	0	−3	−8	−7	−10	−7	−7	−57	1	8	16	7	0	11	7	4	54
1359	June 29	5	6	4	2	1	1	1	0	20	−14	−1	−17	−14	−11	−24	−14	−7	−102	2	7	19	10	1	13	5	3	60
1360	July 26	1	2	2	2	1	0	0	0	8	+1	−9	−23	−11	−6	−9	−17	−22	−96	3	8	19	6	3	12	1	5	57
1361	Aug. 22	1	5	3	2	0	0	1	0	12	−22	−25	−20	−15	−23	−9	−20	−15	−149	10	13	19	8	16	11	3	2	82
1362	Sep. 18	1	2	1	2	1	1	0	2	10	−6	−15	−16	−8	−7	−15	−14	−12	−93	16	19	19	9	11	6	12	5	97
1363	Oct. 15	2	5	4	2	2	2	1	1	19	−7	−16	−15	−16	−20	−21	−13	−19	−127	20	16	18	8	6	13	7	2	90
1364	Nov. 11	2	1	6	2	0	2	3	2	18	−14	−18	−12	−20	−25	−13	−10	−14	−126	10	20	12	2	6	11	7	2	70
1365	Dec. 8	3	5	3	4	0	1	2	1	19	−15	−10	−14	−14	−12	−21	−16	−10	−112	15	11	22	9	2	13	10	13	95
	1933																											
1366	Jan. 4	4	4	6	5	0	0	0	3	22	−12	−8	−14	−20	−18	−9	−12	−7	−100	8	3	0	11	11	13	16	15	77
1367	Jan. 31	9	13	11	6	1	0	0	0	40	−7	−4	−3	−6	−8	−10	−12	−10	−60	6	3	5	2	8	10	22	21	77
1368	Feb. 27	2	2	3	2	0	0	1	4	14	−6	−7	−12	−15	−20	−15	−18	−20	−113	7	4	1	7	9	11	23	22	84
1369	Mar. 26	6	3	1	0	0	0	1	3	14	−21	−12	−13	−17	−14	−16	−28	−19	−140	14	9	11	12	8	4	19	20	97
1370	Apr. 22	0	0	1	1	0	1	0	0	3	−14	−19	−5	−7	−13	−12	−11	−12	−93	15	8	15	15	10	0	9	14	86
1371	May 19	3	3	0	0	2	2	0	2	12	−12	−12	−12	−18	−12	−13	−15	−12	−106	5	3	7	18	7	2	8	15	65
1372	June 15	3	2	1	0	0	0	2	3	11	−11	−16	−6	−9	−27	−22	−13	−17	−121	5	12	3	13	11	6	6	16	72
1373	July 12	1	0	0	0	0	0	0	0	1	−15	−7	−12	−23	−13	−28	−13	−17	−128	2	9	5	16	10	2	0	15	59
1374	Aug. 8	0	1	0	0	0	0	0	1	2	−17	−21	−10	−17	−15	−18	−11	−4	−113	1	11	14	18	13	10	1	7	75
1375	Sep. 4	2	3	0	0	0	2	1	2	10	−15	−17	−16	−14	−16	−9	−12	−7	−106	4	17	17	19	13	7	10	11	98
1376	Oct. 1	0	0	1	0	0	0	0	2	3	−10	−8	−9	−10	−12	−15	−7	−23	−94	3	17	18	18	9	9	5	11	90
1377	Oct. 28	3	1	1	0	0	0	0	0	5	−10	−7	−19	−18	−13	−20	−11	−10	−108	1	9	17	20	10	1	7	10	75
1378	Nov. 24	0	0	0	0	0	1	0	0	1	−19	−15	−7	−22	−18	−7	−10	−14	−112	3	9	9	17	16	6	2	9	71
1379	Dec. 21	0	0	0	0	0	0	1	3	4	−15	−8	−7	−9	−11	−6	−17	−15	−88	4	4	7	14	1	3	2	12	47

TABLE 6—Continued

Rotation		Sunspots R									Wave-radiation W									Particle-radiation P								
No.	First day	Av. (R/5) for eighth								Sum	Av. δW_2 for eighth								Sum	Sums C_8 for eighth								Sum
		a	b	c	d	e	f	g	h		a	b	c	d	e	f	g	h		a	b	c	d	e	f	g	h	
	1934																											
1380	Jan. 17	1	0	0	1	3	1	3	2	11	−11	−10	−10	−18	−17	−8	−12	−19	−105	8	10	9	10	7	10	9	15	78
1381	Feb. 13	3	3	0	1	0	1	2	4	14	−9	−9	−17	−17	−14	−20	−16	−15	−117	10	16	6	7	6	18	18	14	95
1382	Mar. 12	1	1	0	0	1	1	2	1	7	−10	−7	−15	−10	−3	−17	−8	−16	−86	4	11	4	16	12	16	15	16	94
1383	Apr. 8	0	1	6	5	4	3	1	1	21	−3	−5	−9	−15	−9	−15	−2	−6	−64	2	2	7	5	6	2	3	15	42
1384	May 5	5	4	3	6	8	6	3	1	36	−4	−12	−10	−11	+2	−7	−4	−6	−52	4	8	11	4	12	9	3	1	52
1385	June 1	0	0	1	0	4	5	2	1	13	−2	−11	−10	−5	−9	−5	−7	−7	−56	1	15	8	13	8	6	1	4	56
1386	June 28	0	0	1	4	5	4	3	1	18	−19	−22	−10	−4	−8	−9	−7	−13	−92	4	13	7	4	6	7	0	2	43
1387	July 25	1	0	0	1	2	4	5	3	16	−7	−9	−15	−14	−7	−10	−10	−13	−85	1	14	17	11	4	13	7	9	76
1388	Aug. 21	1	1	1	0	0	0	1	4	8	−21	−8	−27	−19	−4	−7	−15	−11	−112	8	10	19	15	9	5	6	4	76
1389	Sep. 17	1	1	0	2	2	1	0	2	9	−14	−16	−12	−14	−7	−10	−9	−11	−93	12	8	19	14	8	9	2	7	79
1390	Oct. 14	2	2	1	1	3	3	3	2	17	−16	−8	−10	−14	−17	−10	−15	−14	−104	9	7	7	21	4	1	5	16	70
1391	Nov. 10	2	0	1	0	1	5	5	3	17	−18	−13	−10	−9	−6	+10	−4	−15	−65	4	4	5	0	11	5	13	15	57
1392	Dec. 7	2	0	0	1	5	8	7	7	30	−8	−7	−14	−10	−2	+1	−8	−7	−55	6	6	7	6	8	13	12	15	73
	1935																											
1393	Jan. 3	5	4	4	5	3	2	6	5	34	−5	−15	−17	−7	−9	−4	−10	+5	−62	8	2	7	9	15	11	15	15	82
1394	Jan. 30	2	2	7	5	5	3	5	4	33	−15	−13	−4	−8	−6	+3	−12	−8	−63	16	10	7	4	19	11	11	13	91
1395	Feb. 26	4	4	3	5	11	11	7	3	48	−15	−18	−16	−24	−18	−16	−12	−7	−126	8	14	7	6	17	19	13	12	96
1396	Mar. 25	2	0	0	1	4	6	6	4	23	−12	−6	−8	−6	−13	−16	−10	−10	−81	4	7	2	3	16	23	11	9	75
1397	Apr. 21	3	1	2	8	12	11	9	6	52	−9	−19	−8	−2	−4	−10	−1	0	−53	4	3	3	14	1	7	12	7	51
1398	May 18	0	1	2	5	7	7	10	14	46	−3	−10	−6	−4	−8	−11	−17	−10	−69	12	4	4	6	2	12	23	14	77
1399	June 14	9	9	8	10	10	7	6	9	68	−11	−16	−10	0	−1	−16	−8	−11	−73	4	18	6	1	12	3	2	15	61
1400	July 11	11	10	11	7	4	1	3	5	52	−4	−3	+13	+12	−10	−6	−6	−3	−7	7	7	6	14	15	4	7	7	67
1401	Aug. 7	8	7	6	6	9	7	5	7	55	+2	−14	−1	+12	−6	−4	−6	−7	−24	4	2	5	7	16	11	10	8	63
1402	Sep. 3	9	10	6	7	7	5	12	15	71	+1	0	−5	−12	−11	−7	−5	−1	−40	11	8	21	9	17	5	22	12	105
1403	Sep. 30	14	12	7	6	13	17	14	13	96	−1	−2	−10	−13	−3	0	−4	+1	−32	13	2	9	13	16	15	18	15	101
1404	Oct. 27	6	4	9	12	14	21	20	14	100	−15	−7	−10	−5	0	+4	+6	+6	−21	18	15	12	8	11	14	6	10	94
1405	Nov. 23	11	12	11	12	16	15	13	10	100	+6	+2	+10	+15	−5	+5	+10	0	+43	2	11	20	5	8	10	19	10	85
1406	Dec. 20	8	13	14	14	13	9	7	12	90	+1	−6	+9	+29	+5	−16	+3	−1	+24	4	12	18	7	1	8	16	12	78
	1936																											
1407	Jan. 16	14	19	20	13	9	10	14	15	114	−5	+5	+11	+7	+9	+8	+2	+8	+45	9	12	18	15	8	11	3	14	90
1408	Feb. 12	16	15	16	20	19	14	12	17	129	+4	+6	+8	+10	−1	+3	+4	−2	+32	8	18	18	15	13	5	4	10	91
1409	Mar. 10	16	13	15	20	12	19	20	17	132	+5	+5	+15	−11	+5	0	+5	+4	+28	1	6	12	19	20	11	10	10	89
1410	Apr. 6	18	19	17	17	14	13	11	7	116	+6	0	+9	−2	+5	−1	+1	+7	+25	7	6	16	19	23	14	4	6	95
1411	May 3	10	10	10	15	11	8	15	14	93	−3	+13	+11	+6	+6	+8	+13	+1	+55	6	2	19	14	19	11	3	12	86
1412	May 30	15	14	14	9	7	12	21	17	109	+12	+11	+6	+2	+12	+7	+15	+15	+80	19	11	7	17	13	14	12	4	97
1413	June 26	19	15	10	8	11	15	12	7	97	+10	+16	+7	−8	−3	+13	+5	−6	+34	7	6	14	15	19	5	13	4	83
1414	July 23	8	10	15	15	18	18	20	21	125	−3	−3	+10	0	−4	−9	+3	−1	−7	2	13	12	8	10	8	5	3	61
1415	Aug. 19	15	14	17	24	15	12	9	16	122	+7	+5	+2	+6	+18	+12	−1	+13	+62	3	4	9	11	5	3	13	5	53
1416	Sep. 15	14	14	22	18	20	22	27	19	156	+4	+13	+7	+6	+22	+14	+20	+9	+95	3	4	10	12	9	2	16	16	72
1417	Oct. 12	18	21	15	11	11	19	28	30	153	+7	+13	+11	+11	+15	+5	+20	+8	+90	6	20	9	13	2	8	14	13	85
1418	Nov. 8	28	27	20	10	9	22	38	36	190	+7	+19	+2	+13	+10	+14	+24	+18	+107	16	8	16	10	1	4	14	12	81
1419	Dec. 5	28	22	15	12	17	27	30	36	187	+13	+9	+3	−4	+16	+14	+17	+33	+101	9	1	11	1	7	1	10	8	48

TABLE 6—Concluded

Rotation		Sunspots R									Wave-radiation W									Particle-radiation P								
No.	First day	Av. $(R/5)$ for eighth								Sum	Av. δW_2 for eighth								Sum	Sums C_8 for eighth								Sum
		a	b	c	d	e	f	g	h		a	b	c	d	e	f	g	h		a	b	c	d	e	f	g	h	
	1937																											
1420	Jan. 1	27	18	19	19	20	23	32	37	195	+28	+22	+21	+19	+10	+13	+20	+21	+154	7	7	18	11	2	7	5	7	64
1421	Jan. 28	43	43	29	17	16	19	21	31	219	+27	+36	+40	+ 1	+13	+18	+23	+23	+181	13	12	20	15	17	15	17	12	121
1422	Feb. 24	34	31	18	20	18	6	6	12	145	+39	+15	+17	+18	+15	+ 3	+10	+ 9	+126	7	15	11	4	3	19	9	10	78
1423	Mar. 23	19	23	28	26	23	16	9	14	158	+23	+11	+18	+15	+15	+ 4	+ 4	+ 4	+ 94	11	17	15	14	5	5	10	7	84
1424	Apr. 19	24	32	32	20	14	11	19	24	176	+10	+17	+13	+ 8	− 7	+12	+ 3	+22	+ 78	11	15	27	17	17	4	12	9	112
1425	May 16	35	34	39	19	19	20	22	18	206	+22	+20	+27	+13	+18	+12	+ 1	+18	+131	7	7	11	20	12	9	17	8	91
1426	June 12	33	37	38	31	20	17	16	28	220	+20	+36	+29	+31	+19	+15	+14	+11	+175	10	13	13	13	13	7	6	14	89
1427	July 9	40	41	34	30	27	25	29	39	265	+25	+ 4	+21	+27	+17	+12	+16	+15	+137	15	14	8	20	21	6	7	21	112
1428	Aug. 5	34	33	26	21	18	26	28	24	210	+29	+32	+48	+21	+25	+ 9	+24	+ 9	+197	7	4	3	4	6	9	9	4	46
1429	Sep. 1	22	18	23	21	17	17	22	21	161	+21	+27	+18	+15	+ 8	+15	+ 7	+15	+126	6	7	12	13	12	8	9	8	75
1430	Sep. 28	24	37	36	32	28	25	30	14	216	+18	+24	+32	+20	+17	+ 4	+ 5	+ 1	+121	10	17	17	25	17	8	3	20	117
1431	Oct. 25	14	22	22	12	12	18	17	17	134	+ 5	+10	+18	+14	+ 7	+10	+ 4	+11	+ 79	19	7	5	2	13	11	1	21	79
1432	Nov. 21	12	14	12	6	11	12	18	27	112	+24	+27	+ 9	+20	+ 1	+ 7	+15	+10	+113	18	9	21	8	8	12	3	1	80
1433	Dec. 18	22	21	24	22	22	18	17	21	167	+ 7	+23	+22	+14	....	....	...	..	.....	21	15	9	4	12	16	12	13	102

TABLE 7—*Eighth-deviations* ΔR, ΔW, *and* ΔP

Yr.	Rotation No.	Sunspots ΔR for eighth								Wave-radiation ΔW for eighth								Particle-radiation ΔP for eighth							
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
1922	1218	−2	−3	−3	+1	+3	+7	−3	−7	....	....	....	....	....	....	....	....	−4	−1	+3	−2	0	+5	+4	−2
	1219	−8	−1	+11	+10	+3	+5	−5	−6	....	....	....	....	....	....	....	....	−10	0	+6	−1	−7	+8	+1	+3
	1220	−6	+1	+3	+2	+2	−2	−2	−2	....	....	....	....	....	....	0	−4	−7	−2	+3	+2	−9	+2	+4	0
	1221	−2	−1	+1	+1	+4	+1	0	−2	+1	−10	+3	−4	+10	−5	−10	+5	−7	+4	+8	0	−9	−2	+9	−2
	1222	−2	−1	−1	+1	+1	0	−2	0	+5	+2	+3	−11	0	+5	0	0	−2	−3	+5	+3	−5	−1	+6	−3
	1223	+1	+2	−1	−1	−1	−2	−1	+1	−5	+2	+7	0	0	−7	+3	−2	−3	−1	+5	−3	−6	+6	+8	−2
	1224	+3	0	−3	−1	+4	+2	−1	−2	+3	+7	−8	−4	+3	−11	+6	+2	−6	−8	+6	+3	−7	+2	+8	−3
	1225	+1	0	−1	−1	−1	−1	+3	+3	+7	+2	+3	−8	−1	−4	+4	0	−4	−6	+10	+5	−9	+1	+2	0
	1226	+1	−2	−2	−1	+1	+1	+1	0	0	−2	−9	−4	+7	0	+1	+7	−2	−6	+5	+3	+6	−3	+1	−10
	1227	0	+1	0	−2	+1	0	+2	0	0	−4	+5	0	−1	+1	0	−1	−1	−2	+10	+8	−2	−3	−5	−3
	1228	−2	−2	0	0	0	+1	+1	−1	−5	+1	−3	+5	+2	0	+1	−2	0	−2	+10	+6	−6	0	−4	−2
	1229	0	−2	−2	+1	+3	+2	0	−3	−2	0	0	0	−3	−1	+4	+2	0	−4	+4	+6	−3	−1	+4	+5
	1230	−3	−3	+1	+6	+5	+1	−3	−2	+6	+2	−7	−6	0	+6	−2	−2	−6	−6	+1	+3	+1	0	−3	−3
1923	1231	−1	−1	0	0	0	+1	−1	0	+2	−10	0	+8	+9	−2	−5	+2	+3	−3	+3	+3	−7	+4	+2	+1
	1232	−1	0	+1	0	0	0	0	0	−2	−2	0	0	+9	−3	−2	+1	0	−4	0	−1	−7	+16	0	−6
	1233	0	−1	0	−1	+1	+1	0	+2	−4	+1	+3	−4	−3	−3	+4	+7	−5	−6	+5	+1	−4	+14	+2	−6
	1234	−1	−1	−1	0	+1	+2	+1	+2	+1	−4	0	+2	+6	−5	+8	−12	−8	−2	+6	+2	−6	+10	0	−6
	1235	−1	−1	−1	0	0	−1	0	+1	+2	−7	+4	+4	+5	−1	+3	−4	−3	+4	+1	−5	−3	+11	−2	−5
	1236	0	+2	0	−1	−1	−2	−1	0	−10	+5	+3	−7	−7	+1	+10	+5	+2	−1	+4	−4	−3	+10	−5	+3
	1237	+2	+3	+3	−1	−2	−1	−1	−1	−3	+5	−17	+4	+6	+2	+2	−8	−7	0	+5	−4	+2	+6	−5	+2
	1238	0	+1	0	0	−1	0	0	0	0	+1	+8	−8	+6	+5	−8	+1	0	−3	0	−5	+6	+1	−2	+6
	1239	0	0	−1	−2	−1	+2	+2	+2	−1	−1	+3	+1	−3	+1	−12	+7	−4	−1	+2	−3	+1	+1	−5	+5
	1240	−1	0	−2	−1	+2	+1	0	−2	+4	+5	−9	0	−2	+8	−1	+1	0	−2	−4	−4	+14	+2	−8	+7
	1241	0	0	−1	−1	+2	+1	0	+2	−7	+6	−4	+6	+1	−6	+6	−6	0	+3	+14	−2	−8	−1	−1	+6
	1242	+1	−1	0	−1	−1	0	+1	0	+5	−3	+8	−6	−1	0	−6	+8	−1	−5	+3	−3	−3	0	+1	+6
	1243	−1	−1	−1	−1	−1	+2	+2	0	−1	−5	−4	+2	+3	+1	−7	−1	−1	−4	+3	+1	−5	−4	+5	+10
	1244	−1	0	0	0	0	0	0	0	+7	+6	+3	−4	−12	+7	−3	+2	−5	−1	−4	+6	−6	0	−6	+8
1924	1245	0	0	0	0	0	0	0	−1	0	−2	+2	+2	+6	+4	0	−12	−1	+8	−5	+5	−3	−6	−3	0
	1246	−2	+3	+3	+1	−1	−1	−1	0	−3	−1	+5	+4	−4	−2	+1	+1	+10	+1	−10	+3	+6	+3	−8	−5
	1247	0	+1	0	0	0	0	−2	−1	0	−1	−2	+5	−1	−3	−4	+1	+7	+1	−5	+8	−4	+4	−5	−5
	1248	−2	+5	+4	0	−4	−4	−2	0	+2	+6	+14	−16	−5	+4	−2	+3	0	+2	+1	+8	−1	−4	−4	−4
	1249	+4	+4	0	−1	−3	−2	+3	+4	−1	+5	−6	−3	−3	+2	+1	+6	−1	−2	+3	+13	+3	−3	−8	−9
	1250	−1	−2	0	−1	−2	−1	−2	+1	+1	+3	−6	+4	−3	−6	−6	+2	+6	+2	−1	+10	+2	−5	−2	−7
	1251	+2	+5	+4	−1	−4	−1	−1	0	+9	+3	+8	−3	−7	−5	−7	+2	−1	+6	−4	+3	+5	−5	+8	−6
	1252	+2	+1	−1	−1	−1	−1	−2	−2	+5	+3	−2	−1	−4	+13	−5	+1	+1	+5	−3	−4	0	+3	−4	−7
	1253	+3	+4	+2	−2	0	−1	−2	0	−6	+1	+4	−2	0	−8	+2	+2	+3	−1	+5	+10	+1	−6	−6	0
	1254	−1	+1	+2	+2	+2	−1	−2	−1	+6	+1	−3	−2	−1	+4	+7	−6	+6	+3	−6	+3	−1	−8	0	0
	1255	0	+2	+1	−1	−3	−4	−2	0	−1	−5	0	+9	−5	+3	−6	+2	+6	+5	−5	+5	−3	−2	−1	−1
	1256	+3	+6	+6	−1	−4	−5	−1	+2	−4	+5	+7	−7	−6	+2	−4	+6	0	−3	+10	+1	−6	−5	−1	+5
	1257	+1	+1	+4	+1	−2	−2	−1	−2	+7	+5	−6	−13	+8	+7	−10	+1	−2	+4	+7	−4	−4	−2	−1	−4

TABLE 7—Continued

Yr.	Rota-tion No.	Sunspots ΔR for eighth								Wave-radiation ΔW for eighth								Particle-radiation ΔP for eighth							
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
1925	1258	0	−1	+2	+2	−1	−3	−3	−1	+7	+5	+1	+4	−2	−2	−7	−3	−5	+1	+14	+5	0	−8	−3	−6
	1259	0	+3	+6	+1	−1	−2	−1	0	+1	+2	+7	−5	−6	+7	−8	+4	+6	+2	−1	+3	−2	+1	−1	−2
	1260	−3	−2	0	+2	+2	−1	+3	0	−3	−3	+7	+5	−4	0	+1	−4	0	+6	−3	+2	−1	−1	−1	−6
	1261	−4	−3	+1	+5	+1	+2	0	−1	+1	−3	0	+2	+1	+8	−1	−2	+4	+1	+6	0	0	−2	−4	−1
	1262	−4	−1	0	0	−2	+3	+5	+1	−1	−1	−5	+5	+7	−12	+5	+2	−2	+2	+7	0	−6	−6	0	−3
	1263	−5	−8	+1	+5	+11	+8	−4	−7	−6	+2	−9	−1	+5	+9	+4	−3	+2	+7	+5	+1	−7	+1	0	−5
	1264	−5	−3	−3	+1	+4	+3	+1	0	−7	−5	+4	−2	+4	+2	+13	−9	0	+7	+8	−4	−5	+3	−4	−1
	1265	0	−3	0	+1	−1	−4	+3	+4	−4	−5	+6	+1	0	−5	−4	+4	−4	+2	+10	−4	−2	+2	+7	−8
	1266	−3	−5	−4	+1	+5	+5	+3	−1	+13	−14	−3	−6	−8	+17	+12	−8	−5	+2	+7	−4	−4	+9	+1	−1
	1267	−5	−4	−2	+3	+4	+4	+1	−4	−5	−10	−2	+9	+5	+9	+2	−6	−11	+6	0	+7	+4	−11	−7	+1
	1268	−7	−4	+2	+9	+9	+3	−5	−4	−9	−1	+3	+4	+4	+5	−7	+2	+6	+6	−2	−8	+11	+3	−7	+3
	1269	−5	−3	−1	−3	−2	+5	+10	+2	−4	−5	+2	−3	+6	−1	+2	0	−10	+3	+8	+6	−6	−5	+1	−5
	1270	−4	−4	−3	−2	+6	+5	+3	+2	+3	−11	−9	+7	+11	−3	−1	−6	−1	+4	+4	0	0	−2	−5	−2
	1271	−1	0	−6	−3	+1	−4	+3	+4	+9	+5	−1	−7	−9	+2	+2	+9	+8	0	−3	−1	−3	+8	+1	−3
1926	1272	+7	−1	−6	−6	−8	−2	+13	+10	−2	+2	−4	+3	−3	−6	+2	+7	0	+6	−4	+3	−11	−1	+3	+3
	1273	−2	−7	−6	0	+7	+3	−3	+5	−6	+7	0	−7	+1	+8	−2	+6	−3	+7	−5	0	+4	+2	−3	−5
	1274	0	−3	0	−2	−1	−3	−2	0	−9	−6	0	−5	+4	+5	−4	+2	+6	+2	−5	+2	−6	−2	+4	−3
	1275	+6	+5	−2	−7	−6	0	+3	+6	+6	+5	+2	−7	−14	−6	0	+8	+12	−5	+3	0	−11	−5	+8	+6
	1276	+3	+1	+2	−2	−7	−3	−1	+4	+5	+10	+7	−3	−11	−6	+4	+6	+5	−5	+4	−2	−7	−7	+9	−3
	1277	+6	+2	−1	−4	−6	0	+9	+7	+4	−5	−11	+1	+7	+2	+4	0	+9	−4	0	−2	0	−1	−1	−1
	1278	0	−3	−5	−7	−8	0	+8	+8	−10	0	+2	−4	−6	+6	+3	0	+6	+2	−1	−3	0	−7	0	+4
	1279	+2	+3	−4	−1	−2	−3	+2	+5	−5	+3	+1	+9	+2	−14	+6	−2	+9	−4	−6	+3	+5	+7	−5	−3
	1280	+1	−2	−4	−3	−5	−1	+7	+8	+2	−1	−2	+4	−3	−9	+7	+4	−5	−3	−8	+6	+4	+5	+4	+10
	1281	+1	+1	−9	−8	+1	+10	+10	−1	+5	−2	−7	−5	+2	+6	+8	+2	−3	−10	−9	+2	−1	−3	+13	+5
	1282	−8	−2	+3	0	+3	−2	−3	−4	−4	−7	−13	+4	+5	+3	0	+7	−8	0	−1	+2	+2	−3	−2	−5
	1283	−6	+2	+8	+3	+2	−3	−5	−1	−9	+2	−6	+7	0	+1	−9	+8	−3	+3	+1	+5	+1	−1	−6	0
	1284	+4	+3	+2	+2	−3	−6	−2	+3	−6	+11	−5	+2	+1	−3	+2	−8	0	−2	0	+1	+1	+1	+1	+8
1927	1285	+8	−2	+1	−2	−5	−11	+2	+10	0	+8	0	+7	+1	−11	−8	−14	−4	−1	−2	−4	+2	+2	−4	−1
	1286	+10	+5	−3	−3	−3	−4	0	−3	+19	+9	+2	+3	−12	−8	+7	−2	−5	+7	+4	+1	−4	−3	+3	0
	1287	−1	0	−4	+3	+11	+7	−7	−12	+8	−2	+2	−3	−5	+7	+1	−2	−5	+2	0	+8	+4	−10	−2	+6
	1288	−5	+1	+3	+8	+9	+3	−5	−5	+1	+3	−13	−2	+8	+6	0	−4	−5	−2	+3	+8	+5	−9	−7	+4
	1289	−5	−5	+2	+3	+6	−4	+1	+2	+9	−11	−2	−2	+8	+5	−8	+1	−6	+1	+8	+5	−8	+2	−1	−1
	1290	+5	−3	−6	−2	+4	+3	−2	−5	−2	−3	+5	+2	+7	−4	0	−5	−4	+3	+2	+3	−6	+6	+1	−3
	1291	−7	0	+7	+8	+6	−2	−6	−4	−2	−3	+2	+6	+6	−9	+2	0	−5	−1	+1	+5	+1	+2	−6	−7
	1292	−2	0	+4	+1	+1	0	−4	−4	−1	−4	0	+4	−4	+4	+1	−1	+1	+11	+2	−4	0	+5	−5	−5
	1293	+1	+5	0	+1	0	+1	−4	−5	−9	−3	+13	+3	+12	−11	−12	−2	−1	−1	+12	−8	−5	+5	−1	+8
	1294	−2	+7	+8	0	+1	−3	−8	−1	−8	+13	+3	+1	−2	+2	−8	+2	+7	+1	−8	−5	−6	+4	−2	−2
	1295	+3	+7	+3	−4	−1	+2	−3	0	+1	−1	+12	+8	−7	+1	−11	+6	+8	+6	+2	−10	−1	+10	0	−2
	1296	−4	−5	+1	+7	+3	+1	+3	−1	−2	−8	+5	+2	+6	−3	−2	−5	−5	−3	0	−2	+3	+5	−5	−5
	1297	−3	−6	+3	+8	0	−7	−7	−1	−1	0	+2	+2	+9	−10	+1	−5	+5	−4	+2	−4	+9	+9	−6	−7
	1298	−1	+3	+3	+4	+2	−3	−2	−3	−1	+4	+4	+15	+6	−14	−8	−8	0	+2	+2	−1	−1	−6	−3	+2

TABLE 7—Continued

Yr.	Rotation No.	Sunspots ΔR for eighth								Wave-radiation ΔW for eighth								Particle-radiation ΔP for eighth							
		a	b	c	d	e	f	g	h	a	b	c	d	e	f	g	h	a	b	c	d	e	f	g	h
1928	1299	0	+11	+3	0	−6	−7	−7	−1	−3	+5	+15	+5	−11	−8	−2	+4	+1	+6	0	+4	−2	−8	+2	0
	1300	+5	+8	+6	−1	−9	−2	+2	+2	+4	0	+4	−10	+6	−5	+4	+3	+6	0	+5	−4	−8	−7	+5	+9
	1301	+7	+2	−4	−7	−5	+1	+8	+8	−2	+2	+2	−1	−6	−6	+2	−4	0	−3	+3	−7	−2	+4	+5	+1
	1302	+4	−2	−9	−10	−4	+5	+9	+11	+7	+7	−1	−3	−9	+8	+8	−4	−7	+2	+6	−1	−4	−8	−3	+2
	1303	+7	−5	−11	−11	−6	0	+15	+9	+2	+1	−3	−7	−8	−1	+14	+5	+6	+6	+4	−6	−10	+5	+3	+1
	1304	+4	−8	−12	−6	0	+6	+10	+5	+2	−7	−13	−2	+1	+5	+11	+17	+4	−6	+5	−6	−2	+7	−5	−5
	1305	−1	−10	−5	+5	+7	+6	−6	−7	−7	0	−19	−9	−8	+18	+24	−9	+3	+6	+7	−7	−6	0	+1	+1
	1306	+2	+6	−1	−2	0	−3	−4	+3	−8	−6	+1	+9	−4	−6	−4	+6	−1	−2	+10	−5	+1	−5	−6	−2
	1307	+6	+2	−2	−4	+3	−1	−7	−2	+2	+3	−1	+4	−13	−3	−3	+6	+9	−6	+4	0	+8	−4	−7	+4
	1308	+5	+12	+5	−5	−9	−3	+3	+4	+9	−5	+9	−5	−1	+4	−3	−2	0	+5	−6	+2	+3	−7	−4	+1
	1309	+2	+1	−3	−5	−2	0	+3	+6	+11	−2	+1	−4	+6	−12	−6	+5	+7	0	+5	−4	+2	−5	−7	+8
	1310	+3	0	−4	−7	−6	0	+8	+4	+6	+6	−7	−11	−5	−1	+5	+11	+7	+3	−9	−1	−6	−1	+7	−1
	1311	+6	+6	−5	−7	−8	0	+4	0	+8	−1	+3	−14	−7	−1	+4	+10	+6	−3	−7	+2	+2	−2	−6	+7
1929	1312	+1	0	+5	+4	+3	+1	−8	−6	−5	+3	−10	+1	+6	−6	−3	+5	+6	0	+2	−7	+2	−4	−1	−1
	1313	−4	+6	+8	+1	−5	−2	0	−1	+7	−2	−5	−3	+3	+4	+1	+7	−5	+7	+3	−9	+8	0	−2	+8
	1314	−2	+2	+7	+5	−1	−6	−4	−2	−14	−4	+7	0	−1	+1	0	+4	−4	−4	0	+6	+2	+3	−1	−2
	1315	−1	0	+1	+3	+3	+1	0	−2	−3	+1	+4	−8	0	−1	+4	−4	−3	+1	−1	−1	−4	+10	−4	−6
	1316	−3	−2	+4	+2	+2	+2	+1	−4	+7	−2	−2	+6	−5	+9	−6	−6	0	+7	+2	−5	−6	+8	+3	−5
	1317	−2	+2	−3	−4	+1	+1	+3	0	+2	+5	−4	−5	−3	+7	+5	−1	+1	0	+1	−2	−5	+10	0	−5
	1318	+1	+4	−1	−1	−1	−1	−1	+2	−1	−2	−6	−6	+11	+11	0	−3	−5	+7	−4	+2	−3	+3	+1	−2
	1319	+2	+3	−1	−2	−3	−1	−4	−3	−8	−1	−1	+1	+4	−1	−2	0	+10	−3	−1	−6	−3	+8	−3	−9
	1320	+1	+10	+7	+1	−3	−5	−6	0	−7	+2	+6	+6	+5	−9	−5	−3	+3	+10	+7	−6	−4	−5	−3	−7
	1321	+4	+1	−1	−2	+1	−4	−2	+1	+8	−2	−4	+4	−3	+2	−8	+5	+8	+8	+6	−7	+4	−1	−6	−6
	1322	+2	+5	+6	0	−6	−6	−4	+4	+3	+4	+5	+5	+3	−6	−13	0	−1	+9	+2	+1	+5	−5	−9	−1
	1323	+2	+4	+2	+1	+1	−5	−9	−2	−12	+12	0	+6	0	−4	−1	−2	+7	+9	+3	−10	+3	−5	−1	−5
	1324	+9	+7	−2	−11	0	+5	+6	+5	+1	+14	−10	−9	−6	+7	+13	0	+2	−5	+11	+2	0	+1	−3	0
	1325	+4	−1	−8	−6	−2	0	+6	+8	+7	−6	+6	−14	−2	+1	−2	0	−5	−5	−1	+13	+5	−9	−3	+2
1930	1326	−2	−7	−6	−2	+7	+8	+4	−2	+12	−4	−3	−1	+10	−3	+1	−2	+4	−5	−3	+4	+3	−8	−8	+12
	1327	−4	−6	−3	−2	+1	+4	+1	−2	+5	−4	−8	−4	−1	+9	+8	−5	+6	−4	+2	+3	+2	−13	−11	+11
	1328	+2	0	−3	−2	0	+2	+3	+1	−8	−1	−2	+1	0	+6	+4	+3	+6	+2	0	0	−2	−6	−3	+7
	1329	+3	−2	−4	−1	−2	+2	+4	0	+2	−1	−9	−4	−2	−1	+11	+6	+4	−2	+1	+4	−3	−1	−9	+8
	1330	−2	−2	0	0	+1	+2	0	−2	0	−10	0	−8	+10	−4	−4	+20	+1	−3	+4	+2	−3	−6	−1	+7
	1331	−1	+6	+2	−1	−3	−4	−1	+2	−8	−5	−12	+5	+5	+7	−3	+6	−1	0	+1	+2	+3	−7	−7	+5
	1332	+2	+1	0	0	0	−2	0	0	−7	+1	−1	0	−5	+2	−3	−3	+1	−1	+3	+7	+2	−7	−7	+6
	1333	+1	0	−2	0	+1	−3	−1	0	+15	+1	0	−8	0	−1	−7	+2	0	−7	−2	+8	+4	+2	−6	+2
	1334	0	+1	+1	+4	+3	+1	−1	−4	+8	+5	−1	−14	+1	−2	+11	0	−2	−6	+3	+7	+2	−3	−8	+5
	1335	−4	−1	+1	0	+1	+1	+4	0	−1	−3	+4	−2	−1	+1	+2	−2	−2	−4	+1	+7	+6	−1	−10	−4
	1336	−3	−4	−1	+5	+5	−1	−4	−4	−1	−6	+8	−3	+1	−2	+4	−2	+4	−2	+1	+9	+3	−1	−3	−7
	1337	−5	−1	+5	+4	+6	+1	−3	−6	−3	+3	−4	−1	+7	+7	+7	−10	+6	−4	−9	+11	+4	−2	+5	−6
	1338	−2	−2	+4	+2	+5	0	−3	−3	+2	−6	0	−1	−9	+5	0	+7	−3	−2	−3	+12	+3	−2	−3	−6

TABLE 7—Continued

Yr.	Rotation No.	Sunspots ΔR for eighth								Wave-radiation ΔW for eighth								Particle-radiation ΔP for eighth							
		a	b	c	d	e	f	g	h	a	b	c	d	e	f	g	h	a	b	c	d	e	f	g	h
1931	1339	-1	-1	+3	+1	+1	0	-2	-4	+6	-2	-6	0	+1	+9	-4	-8	-5	+4	-3	+10	-2	-1	+4	-2
	1340	+1	0	-2	-3	0	+4	+8	+3	-2	+6	+4	-6	+1	+5	+1	-5	+2	-5	-6	+8	+1	-8	+4	+4
	1341	-4	-3	-2	+1	+3	+3	-1	-4	-5	0	-2	+1	+9	+5	-4	-4	-1	-4	+2	+5	-3	-3	+3	+3
	1342	-3	+1	+1	+3	+1	+1	-1	+1	-4	+3	+3	-5	-1	+7	-3	-1	-3	+2	-2	-1	0	-5	+9	0
	1343	+1	-1	-2	-2	0	+2	+1	0	-1	+3	+4	-4	+2	+2	-3	+1	0	-5	-5	+4	-3	+9	+6	-2
	1344	+1	+1	-2	-1	+2	+4	0	-2	-7	+2	-1	+4	+1	+7	-1	-1	-8	0	-4	+6	-2	+4	+5	-5
	1345	-2	-2	-3	+1	+1	0	+3	+3	-6	-7	-1	0	-1	-1	+11	+4	-7	0	+2	+7	+1	-2	-6	+1
	1346	-1	-3	-2	-2	+1	+3	+3	-2	+6	-5	+1	-6	-9	+7	+12	-5	+3	-6	-1	+5	+4	-5	-3	+7
	1347	-2	-2	+1	-2	-2	+3	+2	+1	+1	+1	-1	-13	+2	-3	+6	+5	-1	-4	-2	+3	+4	-3	-5	+3
	1348	-2	+1	+1	+2	-1	-1	0	0	+4	-8	-12	+6	+5	+1	+3	-6	+5	-4	+2	+1	+2	-2	-7	+5
	1349	+1	0	-1	0	-1	0	+1	0	-1	+10	+3	0	-7	-3	+2	+3	+6	-6	-2	-1	+2	+1	-6	+5
	1350	0	+1	+1	-2	-4	-3	+2	+4	+5	-5	-5	+1	-2	+1	+5	+3	0	0	+5	-4	0	+6	-5	-7
	1351	+4	0	-4	-2	+3	+3	-1	-2	-11	+5	-4	-2	+4	+6	-6	-1	+1	-1	+8	-4	+5	+3	-3	-9
	1352	+1	+2	0	0	-2	-1	-1	0	+2	-2	+6	-2	+3	-2	-2	-1	-1	-2	+8	-2	-1	+8	+2	-3
1932	1353	-1	+1	+4	+1	+1	-1	-1	-1	0	-5	0	+8	-2	-3	0	+1	-12	-3	+8	-1	+2	+4	+4	+1
	1354	-2	-3	0	+4	+4	+2	-1	-2	0	-1	-1	+7	0	-4	-3	-6	-10	0	+6	-6	-7	+8	+6	+4
	1355	-2	0	0	-1	+1	+1	+1	-1	+5	+4	-6	+6	+5	-2	0	-3	-9	-3	+4	-7	0	+8	+5	+3
	1356	-2	-1	-1	-1	+3	+4	0	-4	+4	-4	-5	+2	0	-6	+3	+7	-7	0	0	-10	+7	+5	-4	+6
	1357	-2	-2	+1	+4	+3	+1	-1	-3	+3	-5	-2	0	-1	-1	+8	-3	-6	-2	+4	-6	-3	+4	+5	+5
	1358	-2	+2	+3	-3	-1	+1	+2	+2	-8	+7	+4	-1	0	-3	+1	+2	-9	-2	+7	-1	-7	+4	0	-3
	1359	0	+2	0	-1	-1	-1	0	-1	-4	+10	-5	-1	+1	-13	-2	+5	-6	-1	+11	+2	-7	+5	-3	-5
	1360	0	+1	+1	+1	0	-1	-1	-2	+13	+2	-13	0	+7	+7	0	-5	-4	+1	+12	-1	-5	+4	-8	-4
	1361	0	+4	+2	0	-2	-1	0	-1	-4	-6	-1	+4	-5	+7	-5	-1	0	+3	+9	-2	+5	0	-9	-10
	1362	0	+1	0	+1	0	-1	-2	0	+7	-3	-4	+4	+5	-3	-2	0	+4	+8	+8	-3	-1	-6	0	-7
	1363	0	+3	+2	0	0	0	-1	-1	+7	-1	0	-1	-4	-4	+4	-2	+8	+4	+6	-3	-5	+3	-3	-7
	1364	0	-1	+4	0	-2	-1	0	-1	+3	-1	+5	-4	-9	+2	+5	+1	+1	+11	+3	-7	-3	+2	-2	-7
	1365	0	+2	0	+2	-2	-1	-1	-2	-1	+3	0	0	+2	-7	-3	+4	+5	+1	+12	-2	-9	+3	+1	+6
1933	1366	+1	+1	+3	+2	-3	-4	-5	-2	+2	+6	-1	-7	-6	+3	-1	+2	0	-6	-9	+1	+1	+4	+6	+6
	1367	+4	+8	+6	+1	-4	-3	-2	-2	+1	+3	+4	+1	-1	-2	-4	-1	-3	-5	-3	-7	-2	0	+13	+11
	1368	+1	+1	+2	0	-2	-2	-1	+2	+5	+5	0	-1	-5	+1	-1	-3	-3	-6	-9	-3	-2	-1	+10	+8
	1369	+4	+1	-1	-2	-1	-1	0	+2	-4	+4	+4	+1	+3	+1	-11	-3	0	-4	-2	0	-4	-8	+7	+7
	1370	-1	-1	0	0	-1	0	-1	-1	+1	-4	+9	+5	-1	-1	0	0	+2	-5	+3	+4	0	-9	+1	+6
	1371	+2	+2	-1	-1	0	+1	-1	0	+1	+1	+1	-5	+1	0	-2	0	-3	-5	-1	+10	-1	-7	-1	+7
	1372	+2	+1	0	-1	-1	-1	+1	+2	+2	-2	+9	+6	-12	-7	+2	-1	-3	+3	-6	+4	+2	-2	-2	+7
	1373	0	-1	-1	0	0	0	0	0	+1	+9	+4	-7	+3	-11	+5	0	-7	+1	-3	+9	+3	-5	-8	+6
	1374	0	+1	0	0	0	-1	-1	0	0	-4	+6	-2	-1	-4	+3	+10	-8	+1	+4	+8	+3	0	-10	-4
	1375	+1	+2	-1	-1	-1	+1	0	+1	-1	-4	-3	-1	-3	+3	-1	+3	-7	+6	+6	+7	+1	-5	-2	-1
	1376	-1	-1	+1	0	0	-1	-1	+1	0	+2	+1	+1	0	-3	+5	-10	-9	+5	+6	+7	-2	-1	-5	+1
	1377	+2	0	0	-1	0	0	0	0	+4	+7	-4	-4	+1	-5	+4	+4	-9	-1	+8	+11	0	-9	-2	+2
	1378	0	0	0	0	0	+1	0	0	-4	-1	+7	-8	-4	+6	+3	-2	-6	0	0	+8	+7	-3	-6	+1
	1379	0	0	0	0	-1	-1	0	+2	-4	+2	+3	+2	0	+5	-6	-3	-3	-2	+1	+8	-5	-4	-5	+5

TABLE 7—Continued

Yr.	Rotation No.	Sunspots ΔR for eighth								Wave-radiation ΔW for eighth								Particle-radiation ΔP for eighth							
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
1934	1380	0	−1	−1	0	+1	−1	+1	0	+2	+3	+3	−5	−4	+5	+1	−5	+1	+2	0	0	−3	0	−2	+5
	1381	+1	+1	−2	−1	−2	0	+1	+3	+4	+5	−2	−2	+1	−5	−2	−1	0	+3	−5	−5	−6	+7	+8	+3
	1382	0	0	−1	−1	0	0	+1	−1	+3	+5	−4	+1	+7	−7	+1	−7	−8	−1	−8	+4	0	+5	+4	+6
	1383	−2	−2	+3	+2	+1	0	−2	−2	+7	+5	+1	−6	−1	−6	+7	+3	−7	−6	+1	0	+1	−4	−3	+8
	1384	+1	0	−1	+2	+4	+2	0	−2	+4	−5	−4	−5	+8	−1	+2	0	−3	0	+3	−3	+6	+2	−4	−6
	1385	−2	−2	−1	−2	+2	+3	0	−1	+4	−4	−3	+2	−1	+5	+3	+3	−7	+8	+1	+6	+1	−1	−6	−2
	1386	−2	−2	−1	+2	+3	+2	+1	−1	−9	−12	+1	+7	+3	0	+2	−3	−2	+7	+1	−2	+1	+2	−6	−5
	1387	−1	−2	−2	−1	0	+2	+3	+1	+3	+1	−5	−3	+5	+2	+3	+1	−6	+7	+9	+2	−6	+3	−3	−1
	1388	−1	−1	0	−1	−1	−1	0	+2	−7	+6	−13	−5	+10	+7	−2	+1	−3	−1	+9	+5	−1	−5	−4	−6
	1389	0	0	−1	+1	+1	0	−1	+1	−2	−4	0	−2	+5	+1	+2	0	+2	−2	+9	+4	−2	0	−7	−1
	1390	+1	0	−1	−1	+1	+1	+1	0	−5	+4	+2	−1	−4	+4	−1	0	+1	−1	0	+13	−4	−7	−3	+10
	1391	0	−2	−1	−2	−1	+3	+3	+1	−5	−2	−1	−1	+2	+16	+2	−8	−1	−2	−2	−7	+4	−3	+5	+7
	1392	0	−3	−3	−3	+1	+4	+2	+2	−2	0	−6	−3	+5	+8	0	+1	−2	−3	−2	−3	−1	+4	+3	+6
1935	1393	−1	−1	−1	+1	−1	−2	+2	+1	+3	−6	−8	+1	−1	+5	−2	+12	−2	−8	−3	−1	+4	−1	+3	+3
	1394	−2	−2	+3	+1	+1	−1	+1	0	−8	−7	+2	−1	+2	+11	−3	+3	+4	−2	−5	−8	+8	0	0	+2
	1395	0	−1	−3	−1	+5	+5	+2	−2	−2	−3	0	−8	−2	−1	+1	+5	−3	+3	−5	−6	+5	+8	+3	+2
	1396	−2	−3	−3	−2	+1	+3	+3	0	−2	+4	+2	+4	−3	−5	+1	+1	−6	−3	−8	−7	+7	+14	+2	−1
	1397	−2	−5	−4	+2	+6	+5	+3	0	+1	−10	0	+5	+2	−5	+4	+5	−5	−5	−4	+7	−6	0	+4	0
	1398	−5	−4	−3	0	+1	0	+2	+5	+2	−5	0	+4	+1	−1	−6	+1	+5	−3	−4	−3	−7	+2	+13	+4
	1399	0	−1	−1	+1	+1	−2	−3	0	−1	−6	+1	+9	+8	−9	−3	−8	−7	+7	−3	−7	+4	−4	−5	+8
	1400	+3	+2	+4	0	−2	−5	−2	0	−1	0	+15	+13	−9	−5	−4	0	−1	−2	−3	+5	+7	−4	0	0
	1401	+3	+1	0	−1	+2	0	−2	0	+5	−11	+1	+15	−3	−2	−4	−4	−2	−5	−3	−1	+8	+2	0	−4
	1402	+2	+3	−1	−1	−2	−5	+2	+5	+6	+6	+1	−7	−6	−2	+1	+5	−1	−4	+9	−4	+4	−8	+10	+1
	1403	+4	+1	−5	−6	+1	+7	+4	+2	+5	+3	−6	−9	+2	+6	+2	+7	+1	−10	−3	+1	+3	+1	+3	0
	1404	−5	−7	−3	0	+1	+7	+6	0	−10	−2	−6	−2	+1	+3	+4	+1	+4	+1	−1	−4	0	+4	−4	0
	1405	−3	−2	−2	−1	+4	+3	+1	−3	0	−4	+4	+9	−10	+3	+6	−4	−8	+2	+10	−6	−3	−1	+8	−1
	1406	−5	+1	+3	+3	+1	−3	−6	−1	−5	−11	+5	+26	+2	−19	−1	−3	−7	+2	+8	−3	−9	−2	+6	+1
1936	1407	+1	+6	+7	−1	−5	−4	0	+1	−6	+2	+6	+2	+3	+1	−5	+1	−3	0	+6	+4	−3	−1	−9	+2
	1408	+1	−1	0	+4	+3	−2	−4	+1	−2	+1	+3	+5	−5	−1	0	−6	−4	+6	+6	+3	+2	−5	−5	+2
	1409	+1	−2	−1	+4	−5	+2	+2	−1	+2	+2	+12	−14	+1	−3	+2	+1	−8	−4	+1	+8	+9	−1	−2	−2
	1410	0	+2	+1	+2	0	0	−1	−4	+3	−3	+6	−5	+2	−4	−3	+3	−6	−7	+3	+7	+11	+2	−7	−5
	1411	−1	−1	0	+4	−1	−4	+2	+1	−8	+7	+4	−1	−2	−1	+5	−7	−5	−8	+9	+4	+7	−2	−10	0
	1412	+3	+2	+1	−4	−7	−2	+7	+3	+4	+3	−2	−7	+2	−3	+5	+5	+7	−1	−6	+4	+2	+4	+2	−7
	1413	+5	+1	−4	−5	0	+5	+2	−4	+2	+8	−1	−14	−6	+12	+5	−7	−4	−5	+4	+5	+9	−5	+3	−6
	1414	−4	−3	+2	0	+2	+1	+3	+3	−5	−3	+11	+1	−4	−10	+2	−2	−7	+4	+4	0	+2	+1	−1	−3
	1415	−3	−4	0	+8	0	−3	−6	+1	+5	0	−4	−1	+10	+4	−10	+4	−3	−2	+3	+5	−2	−4	+6	−2
	1416	−1	−2	+4	−1	0	+2	+7	−1	−5	+3	−4	−6	+10	+2	+8	−4	−4	−3	+3	+4	0	−8	+5	+5
	1417	−1	+3	−3	−7	−9	−2	+7	+8	−6	+1	0	0	+4	−7	+9	−3	−5	+9	−2	+2	−9	−3	+3	+2
	1418	+6	+5	−2	−13	−15	−1	+15	+13	−4	+8	−10	0	−4	0	+11	+6	+5	−2	+6	0	−9	−5	+6	+5
	1419	+5	−2	−9	−11	−6	+4	+7	+12	+2	−3	−8	−16	+2	−1	0	+13	+2	−6	+4	−5	+1	−5	+3	0

TABLE 7—Concluded

Yr.	Rotation No.	Sunspots ΔR for eighth								Wave-radiation ΔW for eighth								Particle-radiation ΔP for eighth							
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
1937	1420	+3	−6	−5	−5	−5	−5	+2	+6	+7	+2	0	−1	−9	−7	−2	−1	−1	−1	+10	+3	−6	−2	−5	−3
	1421	+13	+13	0	−11	−11	−7	−3	+7	+6	+14	+18	−21	−10	−5	+3	+3	+2	0	+6	0	+2	0	+3	−1
	1422	+10	+8	−3	+1	+1	−10	−10	−5	+18	−5	−1	+1	0	−11	−3	−4	−4	+4	+1	−6	−7	+9	−2	−2
	1423	+1	+5	+9	+6	+3	−5	−13	−8	+10	−2	+5	+3	+4	−6	−7	−6	−1	+5	+4	+3	−5	−5	−1	−5
	1424	+3	+12	+12	−1	−9	−13	−5	0	+2	+10	+5	−1	−17	+1	−9	+8	−2	+1	+13	+3	+3	+9	0	−2
	1425	+10	+8	+13	−7	−7	−6	−4	−9	+6	+3	+10	−4	+2	−5	−17	−2	−4	−4	0	+9	0	−3	+4	−4
	1426	+6	+10	+11	+4	−8	−12	−13	0	−1	+15	+7	+9	−3	−5	−4	−6	−2	+1	+2	+2	+2	−5	−6	+2
	1427	+11	+11	+3	−2	−6	−7	−2	+9	+8	−13	+5	+10	0	−7	−7	−9	+2	+1	−5	+6	+7	−6	−4	+11
	1428	+5	+5	−2	−6	−8	+2	+5	+2	+5	+7	+23	−4	+1	−14	+3	−10	−1	−3	−5	−3	0	+3	+2	−4
	1429	0	−4	+2	+1	−3	−5	−2	−4	+4	+10	+2	0	−8	0	−9	−2	−3	−2	+3	+4	+2	−2	−2	−4
	1430	−2	+9	+8	+5	+2	0	−3	−7	0	+6	+15	+4	+3	−9	−6	−9	−4	+3	+3	+11	+2	−7	−11	+8
	1431	−5	+5	+5	−5	−5	+2	+2	+3	−4	+2	+9	+5	−4	−3	−10	−3	+9	−3	−5	−8	+3	+1	−10	+9
	1432	−1	+1	−1	−7	−4	−4	+1	+8	+10	+14	−5	+6	−12	−5	+3	−3	+6	−3	+9	−3	−2	+1	−7	−8
	1433	+2	0	+2	+1	+1	−3	−4	0	....	....	....	....	....	....	....	....	+12	+5	−2	−8	0	+4	−2	−3

TABLE 8—*Sample of table of decade-deviations* Δ_3
(*Complete table may be readily derived from Table* 7)

Rotation No.	$\Delta_3 R$ for eighth								$\Delta_3 W$ for eighth								$\Delta_3 P$ for eighth							
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
1417	0	0	− 2	− 6	− 6	− 1	+ 4	+ 7	− 3	− 2	0	+ 1	− 1	+ 2	0	+ 1	+ 3	+ 1	+ 3	− 3	− 3	− 3	+ 1	+ 3
1418	+ 6	+ 3	− 3	−10	−10	0	+ 9	+11	0	− 2	− 1	− 5	− 1	+ 2	+ 6	+ 6	+ 2	+ 3	+ 1	− 1	− 5	− 3	+ 2	+ 4
1419	+ 5	− 2	− 7	− 9	− 4	+ 2	+ 8	+ 7	+ 2	− 3	− 9	− 7	− 5	0	+ 4	+ 7	0	0	− 2	0	− 3	0	− 1	+ 1
1420	+ 3	− 3	− 5	− 5	− 5	− 3	+ 1	+ 7	+ 7	+ 3	0	− 3	− 6	− 6	− 3	+ 1	− 1	+ 3	+ 4	+ 2	− 2	− 4	− 3	− 2
1421	+11	+ 9	+ 1	− 7	−10	− 7	− 1	+ 5	+ 6	+13	+ 4	− 4	−12	− 4	0	+ 8	0	+ 3	+ 2	+ 3	+ 1	+ 2	+ 1	− 1

TABLE 9—*Sample of table of smoothed decade-deviations* Δ_3^3
(*Complete table may be readily derived from Table* 7)

Rotation No.	$\Delta_3^3 R$ for eighth								$\Delta_3^3 W$ for eighth								$\Delta_3^3 P$ for eighth							
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
1417	+ 2	+ 1	− 2	− 5	− 5	+ 1	+ 5	+ 7	− 1	− 2	− 1	− 1	0	+ 4	+ 3	+ 2	+ 1	+ 1	+ 2	− 1	− 3	− 2	+ 1	+ 3
1418	+ 4	0	− 4	− 8	− 7	0	+ 8	+ 8	0	− 2	− 3	− 4	− 2	+ 1	+ 3	+ 5	+ 2	+ 1	+ 1	− 1	− 4	− 2	+ 1	+ 3
1419	+ 5	− 1	− 5	− 8	− 6	0	+ 6	+ 8	+ 3	− 1	− 3	− 5	− 4	− 1	+ 2	+ 5	0	+ 2	+ 1	0	− 3	− 2	− 1	− 1
1420	+ 6	+ 1	− 4	− 7	− 6	− 3	+ 3	+ 6	+ 5	+ 4	− 2	− 5	− 8	− 3	0	+ 5	0	+ 2	+ 1	+ 2	− 1	− 1	− 1	− 1
1421	+ 7	+ 4	− 1	− 4	− 6	− 5	− 3	+ 2	+ 6	+ 7	+ 1	− 2	− 7	− 5	− 3	+ 3	0	+ 2	+ 2	0	− 1	− 1	0	− 2

lower values, one may roughly take a change of C_{int} by a little more than 0.2 unit as corresponding to a change of C_8 by one unit. Therefore a change of eighth-values (here sums) of ΔP, $\Delta_3 P$, and $\Delta_3^3 P$ by one unit corresponds to a change of C_8 by about (8/27) unit, or of C_{int} by about 0.06.

§ 14. *Inter-correlation and auto-correlation*

Ordinary correlation-coefficients $r(\Delta_3 R, \Delta_3 W)$, $r(\Delta_3 R, \Delta_3 P)$, and $r(\Delta_3 W, \Delta_3 P)$ were computed for the decade-deviations, for each year separately. It was convenient to regard each "year" as comprising a full number of rotations, beginning with the first rotation starting in the calendar year; in Table 10, the numbers of these first rotations, their first days, and the total number n of decade-deviations in each "year" are given, with 1922 (first full rotation No. 1221) and 1937 (last full rotation No. 1432) incomplete.

In Table 10, the prefix Δ_3 has been omitted everywhere. The fifth column characterizes the solar activity (in the ordinary calendar year) by the mean sunspot-number. The next three columns give standard deviations σ. The correlation-coefficients r follow, for clearness multiplied by 100. In addition to this "inter-correlation" between simultaneous decade-deviations for the three possible pairings of the three phenomena, coefficients r_{27} were calculated, measuring the auto-correlation due to 27-day recurrence, for each phenomenon separately; for instance, the value $100r_{27} = +42$, in the column marked R for the year 1925, means that the correlation-coefficient is +0.42 for the decade-deviations $\Delta_3 R$ for 1257*a* paired with 1258*a*, 1257*b* paired with 1258*b*, . . . , 1270*h* paired with 1271*h*.

The three last lines of Table 10 are simple arithmetical averages; half of the 16 years (namely, 1922-24, 1930-34) were reckoned as "sunspot-minimum," the other half as "sunspot-maximum." It happens that these two groups practically coincide with groups separating the descending parts and the ascending parts of the sunspot-cycles—a grouping which is essential for P.

The main results of Table 10 are: The inter-correlation between $\Delta_3 R$ and $\Delta_3 W$ is quite distinct in all years, except near sunspot-minimum. This is the first proof for the assertion that the changes of the sunspot-numbers R within a solar rotation are reflected in W.

The inter-correlation between $\Delta_3 R$ and $\Delta_3 P$ is definitely weaker, and that between $\Delta_3 W$ and $\Delta_3 P$ is insignificant.

The recurrence-tendency, measured by the auto-correlation r_{27}, is naturally distinct in $\Delta_3 R$, but even higher, at least in the descending phase of the cycles, in $\Delta_3 P$. In $\Delta_3 W$, it disappears around sunspot-minimum, but is significant in the other years.

Another cognate feature is expressed in the standard deviations σ,

which indicate the magnitude of the decade-deviations, that is, the intensity of the changes occurring within single solar rotations: $\sigma(\Delta_3 R)$ is higher in sunspot-maximum than in minimum, as could be expected. $\sigma(\Delta_3 W)$ behaves less distinctly, but still similarly to $\sigma(\Delta_3 R)$; $\sigma(\Delta_3 P)$, however, hardly depends on the phase in the cycle.

Table 10—*Correlations for decade-deviations* Δ_3

Year	First rotation		n	Mean R	Standard deviation			Inter-correlation $100r$ for			Auto-correlation $100r_{27}$		
	No.	First day			R	W	P	R,W	R,P	W,P	R	W	P
1922	1221	Apr. 17	80	14	1.3	2.3	2.4	−5	−9	−21	+30	−7	+57
1923	1231	Jan. 12	112	6	0.8	3.0	2.1	−5	+2	+2	+21	−23	+28
1924	1245	Jan. 25	104	17	1.6	2.6	2.6	+45	+20	−11	+39	−5	+52
1925	1258	Jan. 10	112	44	2.8	3.2	2.6	+63	−18	−2	+42	+16	+32
1926	1272	Jan. 23	104	64	3.3	3.2	2.6	+47	+50	+34	+45	+19	+33
1927	1285	Jan. 9	112	69	3.3	3.7	2.5	+42	+21	−1	+36	+44	+19
1928	1299	Jan. 22	104	78	4.3	4.5	2.5	+60	+37	+30	+65	+44	+31
1929	1312	Jan. 7	112	65	2.8	3.1	2.6	+34	+23	+7	+32	+14	+36
1930	1326	Jan. 20	104	36	2.2	3.0	2.7	+12	+15	−33	+49	+31	+67
1931	1339	Jan. 6	112	21	1.5	2.6	2.0	+31	+3	−12	+7	+8	+48
1932	1353	Jan. 19	104	11	1.2	2.2	2.8	0	+29	−5	+36	−5	+74
1933	1366	Jan. 4	112	6	1.5	2.2	3.3	+16	−32	−36	+44	+26	+69
1934	1380	Jan. 17	104	9	1.3	2.5	2.7	+39	+9	−22	+51	+34	+47
1935	1393	Jan. 3	112	36	2.1	3.3	1.9	+46	+29	+3	+38	+28	+40
1936	1407	Jan. 16	104	80	3.4	2.9	2.9	+58	+29	−2	+53	+25	+56
1937	1420	Jan. 1	104	114	5.1	5.1	2.7	+61	+24	+21	+62	+53	+16
Means:													
Sunspot-minimum				15	1.4	2.6	2.6	+17	+5	−17	+35	+7	+55
Sunspot-maximum				69	3.4	3.6	2.5	+51	+24	+11	+47	+30	+33
All years				42	2.4	3.1	2.6	+34	+14	−3	+41	+19	+44

Similar calculations, started for eighth-deviations Δ, have been discontinued when it was realized that decade-deviations Δ_3 were more appropriate. The results obtained for nine years are given in Table 11. Comparison with the averages obtained for the same nine years with decade-deviations (the last line in Table 11 is computed from Table 10) shows: The average magnitude (measured by σ) of the decade-deviations Δ_3 is distinctly smaller than that of the eighth-deviations Δ; the ratios of the respective standard deviations are, for R and W, about the same, namely $\sigma(\Delta_3)/\sigma(\Delta) = 0.6$, while this ratio for P is 0.77. The ratio measures the

degree of "conservation" in the time-series $\underline{\Delta}$; for independent values, with no conservation, the ratio would be $1/\sqrt{3} = 0.58$ [see 9]. The auto-correlations r_{27} in the Δ_3-values are, in R and W, higher than in the Δ-values, thereby justifying the preference for the Δ_3-values of W as being less affected by statistical uncertainties. Only ΔP and $\Delta_3 P$—on which, however, the interest is not centered at present—give practically identical values for r_{27}.

TABLE 11—*Auto-correlation for eighth-deviations* Δ

Year	Standard deviations σ			100 r_{27}		
	R	*W*	*P*	*R*	*W*	*P*
1922	1.9	4.6	5.0	+25	+ 2	+61
1923	1.1	5.4	5.2	+27	−13	+51
1926	4.8	5.8	5.0	+34	+17	+31
1928	5.9	7.4	5.0	+57	+25	+20
1930	3.0	5.8	5.3	+42	+17	+71
1931	2.1	4.9	4.4	+ 1	0	+50
1932	1.8	4.6	5.7	+25	+ 9	+67
1933	1.7	4.3	5.4	+39	+ 2	+65
1937	6.7	8.0	4.9	+55	+23	+15
Av. dev'ns:						
Eighth Δ	3.2	5.6	5.1	+34	+ 9	+48
Decade Δ_3	1.9	3.3	3.9	+40	+16	+47

§ 15. *The superposed-epoch method*

While the correlation-coefficients are suitable measures for the closeness of the statistical relationship, another line of study—more imitative of the procedure of a laboratory experiment, not possible in work on cosmical phenomena—is an extension of the *superposed-epoch method* (or *synchronization*) due to Chree [see 3, Chapter 12]. It will be shown later that this method is more nearly related to that of correlation than has sometimes been realized, and this will help to avoid possible misconceptions.

The original application of this method [3] contemplated a time-series of a single variable x as a function of time t, namely, daily values for C_{int} as a measure for P. A rule was introduced for selecting epochs t_ν, for instance, the days with the five highest values of x in a calendar month; $\nu = 1, 2, \cdots, n$. For each epoch t_ν, a line of values x is written with $x(t_\nu)$ in the center, say, $x(t_\nu + \tau)$, in columns τ running from $\tau = -T$ to $+T$. The *average line*, consisting of the successive averages of the columns, is regarded as indicating the typical influence on x of the event for which the epochs were selected. The tendency of high or low values of C_{int} to recur after $\tau = 27$ days, as reflection of the solar rotation-period, was thus established.

Here, *two* time-series x and y will be treated simultaneously. The epochs t_ν will be selected first according to well-defined events in x, for instance, high or low values, sudden increases or decreases, etc., and average lines will be formed for both x and y. Now it is important to realize that this "*statistical experiment*" is biased, because the selection of epochs is based on x alone; therefore, it must be supplemented by a *twin experiment* in which the epochs are chosen according to y. If, for instance, the epochs chosen first are selected for high values (positive pulses) in x, and if x and y stand in positive correlation, then the twin experiment would choose high values in y; in order to make the twin experiments comparable, the rules for selection might be defined so that in both experiments about the same number n of epochs would meet them. In the case of high positive correlation between x and y, most epochs will nearly coincide in both experiments; but the weaker the correlation, the fewer epochs will be identical, and the less the twin experiment could be dispensed with.

The results of such experiments will be discussed now; they are all made to study the relation between R and W, while P is carried along for completeness only, since for the study of P and its relation to R, much more material is available than, so far, for W.

§ 16. *The main Experiments 1 to 6*

With three variables R, W, and P, six main experiments are possible: Selection of high values, or positive pulses (No. 1 to No. 3) and of low values, or negative pulses (No. 4 to No. 6), Experiments 1 and 4 are selected according to R, 2 and 5 according to W, 3 and 6 according to P. Times near sunspot-minimum were excluded, so that the cases date mainly from the years 1925-30, 1935-37. A number $n = 30$ seemed adequate, that is, about one selected epoch in every two or three rotations.

The selection was made according to the decade-deviations Δ_3. In Experiment 1, for instance, the positive pulses in $\Delta_3 R$ had to satisfy the condition that the sum of two successive values $\Delta_3 R$ (epoch $\tau = 0$ between them) exceeded $+10$; expressed in sunspot-numbers R, this means roughly that R for one solar hemisphere (bounded by meridians) exceeds R for the opposite hemisphere by at least 50. The actual calculation was carried out with eighth-deviations Δ; the average lines expressed in decade-deviations (these numerical tables are omitted here) are the basis for part of the following discussion. For the diagram (Fig. 1), the average lines of the eighth-deviations were smoothed according to $[(a + 2b + 2c + d)/6]$; thus, the smoothed values refer to $\tau = 0$, $\tau = \pm 1, \pm 2, \cdots, \pm 11$ eighths, and have roughly the character of decade-deviations. The scales are expressed in familiar units, with the approximations given in § 13.

It is convenient to distinguish between "*selected curves*" (one in each

experiment, namely, $1R$, $2W$, $3P$, $4R$, $5W$, $6P$), and "*coordinated curves*" (here the two other average lines in each experiment).

Each curve shows near the center a *main pulse*. The recurrence-tendency shows in weaker *secondary pulses* preceding and following within about a rotation (= 8 eighths). They are separated from the main pulse by *counter-pulses*, about half a rotation from the main pulse; their presence is, of course, arithmetically necessitated by the use of deviations, with which averages over intervals of 27 days must approach zero.

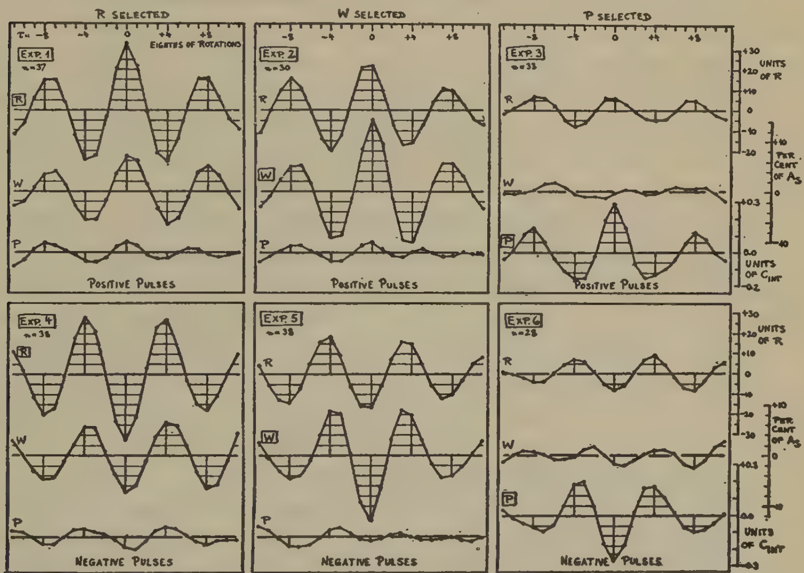

FIG. 1—RESULTS OF THE SUPERPOSED EPOCH FOR EXPERIMENTS 1 TO 6 (CHANGES IN SOLAR ACTIVITY R IN THE COURSE OF A SOLAR ROTATION ARE ACCOMPANIED BY PARALLEL CHANGES IN WAVE-RADIATION W; n=NUMBER OF SELECTED EPOCHS)

Main result—Each pulse in R is accompanied by a nearly simultaneous pulse of the same sign in W, and vice versa. In other words, the wave-radiation reacts to changes in solar activity with no appreciable lag. This will be analyzed more closely:

(*a*) First of all, it is of interest to note that the pulses are quite strong. In Experiment 1, the main pulse in R is about 60 units higher than the counter-pulses, and in Experiment 4 it is about as much lower. Within the interval of 27 days elapsing from $\tau = -4$ to $+4$ eighths, solar activity undergoes therefore a change comparable to the difference between sunspot-minimum and maximum. The differences between the accompanying main pulses in W reach 13 per cent of the average amplitude $A_{S;R=50}$, or 13γ. In the Experiments 2 and 5 (twins, respectively, to 1 and 4), the pulses in W differ by nearly 25 per cent (or 25 γ) in A_S, and in R by about 40 units.

(*b*) In Experiments 1, 2, 4, and 5, closer inspection shows a slight lag

of W behind R. Part of it is due to the differing times of observation: R is estimated at Zürich preferably in the morning, varying with the season, say, roughly, about $07^h\ 00^m$ GMT, while A_S measures W for the five hours centered at about $16^h\ 30^m$ GMT. While it is gratifying to note that the "experiments" permit tracing this trivial difference in the epochs of observation, there remains a slight *actual* lag which, by more detailed scatter-analysis not to be reproduced here, can be narrowed down to between 0.0 and 1.0 day.

(*c*) The times between the main pulse and the two counter-pulses appear somewhat shorter than half a rotation, indicating that the main pulse is a sharper peak than that of a sine-wave of the period of one rotation. This feature is specially distinct in Experiments 3 and 6 in the selected curves for P. Its cause lies partly (especially for the selected curves) in the adopted rule for selecting the epochs (see § A3), but also in the "Randverdunklung" discussed in helio-physics, differing for R, W (wide-angle radiation), and P (conical beam). In R and W, the recurrence-interval (between main and secondary pulses) appears somewhat shorter than one rotation, while in P (Experiments 3 and 6) the interval is clearly 27 days. The significance of this feature in R and W is limited by the small number of cases; that it is clearer in the *selected* curves for R and W than in the *coordinated* curves for R and W causes doubt whether systematic influences play a part, connected with the fact that the probability of an active area on the Sun surviving a time-interval i decreases with increasing i. All curves in Figure 1 resemble those for damped oscillations.

(*d*) The strength of the recurrence-tendency is indicated by the ratio of the secondary to the main pulses. However, for purely statistical reasons (see § 16*f*), the main pulse is exaggerated in the selected curves; it is therefore safer to calculate the ratio from coordinated curves, unless these, as in P, are indistinct.

It appears that the recurrence-tendency is about equally high for R and W. As to P, comparison of the P-curves in Experiments 3 and 6 with the W-curves in Experiments 2 and 5 suggests that the recurrence-tendency is just as distinct in W as in P, for which it has been, since Chree's papers, a classical phenomenon.

(*e*) What is the *quantitative* relation of the main pulses in R and W? If R increases by, say, 50 units either *fast*, in the course of two weeks = about half a solar rotation, or *slowly*, within three years in the ascending part of the 11-year cycle, is the effect on W of the same magnitude in both cases?

The answer (for fast variations) depends on the ratio of the pulses in R and W. This differs appreciably in the twin experiments, because of the statistical exaggeration of the selected main pulse (§ 16*f*). A detailed analysis shows: The linear relation between monthly and annual means of δW_1 and R, that is, for *slow* variations, because of the high correlation, is

fairly well defined as $\delta W_1 = 2/3\ (R - 50)$, as derived in [2], so that, because $\delta W_2 = 0.4\ \delta W_1$, one should expect $\delta W_2 = 0.27\ (R - 50)$ in the *fast* variations, if the quantitative relation for fast and slow variations were equal.

If this was to be tested in the observations, it seemed advisable to use material for fast variations with as high a correlation-coefficient as possible, because, with low correlation, the wide scattering increases the angles between the regression-lines and makes the test vague (see § 16*f*). Therefore, smoothed decade-deviations $\Delta_3^3 R$ and $\Delta_3^3 W$ were compared. The point-cloud (Fig. 2*a*) has the axis *CC*, with the equation $\delta W_2 = 0.19\ (R - 50)$.

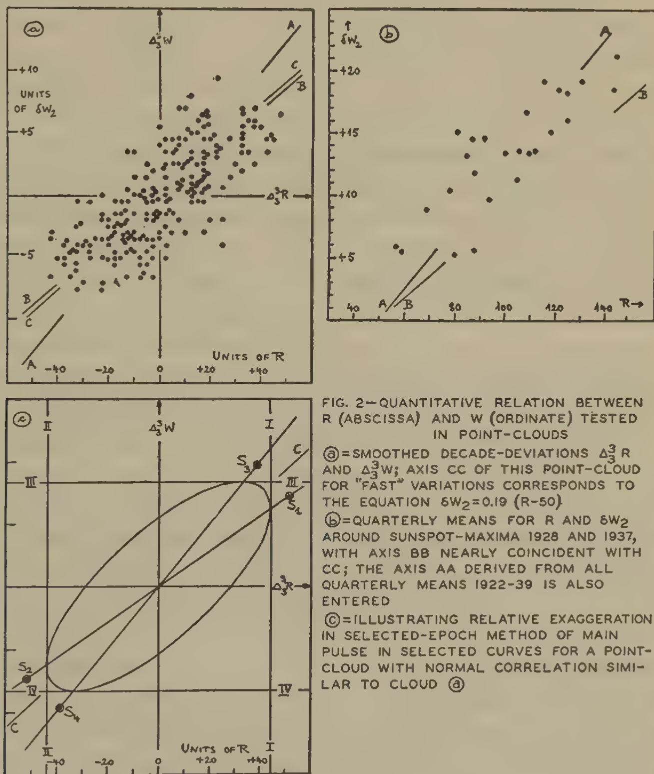

FIG. 2—QUANTITATIVE RELATION BETWEEN R (ABSCISSA) AND W (ORDINATE) TESTED IN POINT-CLOUDS
ⓐ=SMOOTHED DECADE-DEVIATIONS $\Delta_3^3 R$ AND $\Delta_3^3 W$; AXIS CC OF THIS POINT-CLOUD FOR "FAST" VARIATIONS CORRESPONDS TO THE EQUATION $\delta W_2 = 0.19\ (R-50)$
ⓑ=QUARTERLY MEANS FOR R AND δW_2 AROUND SUNSPOT-MAXIMA 1928 AND 1937, WITH AXIS BB NEARLY COINCIDENT WITH CC; THE AXIS AA DERIVED FROM ALL QUARTERLY MEANS 1922-39 IS ALSO ENTERED
ⓒ=ILLUSTRATING RELATIVE EXAGGERATION IN SELECTED-EPOCH METHOD OF MAIN PULSE IN SELECTED CURVES FOR A POINT-CLOUD WITH NORMAL CORRELATION SIMILAR TO CLOUD ⓐ

This would mean that the fast variations in R change W only by $(0.19/0.27) = 70$ per cent of the effect on W caused by slow variations of R.

This result should, however, not be stressed too much, for several reasons. Indeed, Figure 2*a* gives the impression that the line *AA* [with the equation $\delta W_2 = 0.27\ (R - 50)$ for slow variations] fits the point-cloud for fast variations not much worse than the exact least-square axis *CC*. Furthermore, it should be taken into account that the *great* numerical values

of $\Delta_3^3 R$ and $\Delta_3^3 W$ occur near sunspot-maximum, when R, even in decade-averages, goes up to 180, while those slow variations in monthly and annual means from which the linear relation with the factor 0.27 was derived [2], hardly exceed $R = 120$. Now, in the point-clouds for monthly means of R and W [see the diagrams Abb. 16 and 17 in 2], there is already an indication that the regression-curve does not remain linear for high values of R, but curves downward, so that W seems to increase less rapidly for an increase of R from, say, 100 to 130, than from 40 to 70. To demonstrate this, quarterly means (to be exact, overlapping averages of the eighth-values for three successive rotations) for R and W were formed for the sunspot-maxima 1928 and 1937; these were plotted in the point-cloud in Figure 2*b*. Its axis is parallel to a line BB, less steep than AA, and nearly coincident with CC in Figure 2*a*.

These considerations, and other ones based on the Experiments 1 to 6, support the view that there is *only a negligible quantitative difference in the influence of slow and fast variations in sunspot-numbers on wave-radiation.*

(*f*) The *relative exaggeration of the main pulses in the selected curves* has a reason well-known in correlation: Consider a point-cloud, abscissas x, ordinates y, with normal correlation, mass-center in the origin, equal standard deviations σ_x and σ_y, correlation-coefficient r. The lines of equal point-density are then ellipses with the squared ratio of the major and minor axes equal to $[(1 + r)/(1 - r)]$; the directions of the axes are 45° and 135°. The selection of positive pulses in x is then equivalent to the choice of all points to the right of a line II (Fig. 2*c*). The average main pulses in x and y are then given by the coordinates of the mass-centers S_1 of all these selected points. Similarly, the coordinates of S_2, S_3, and S_4 give the main pulses (selected and coordinated) for the average lines of the experiments selecting negative pulses in x, and positive or negative pulses in y (see Fig. 2*c*). The lines S_1S_2 and S_3S_4 are the regression-lines; geometrically, they are the conjugated diameters of the ellipses to their vertical and horizontal diameters.

If, now, $x = X + \xi$, $y = Y + \eta$, with X and Y standing in an exactly linear relation (ideal line), and ξ, η superposed uncorrelated "residuals"—for instance, observational errors in X and Y—the question is how to find, from the point-cloud for x, y, the ideal line connecting X, Y. If $\xi = 0$, the ideal line is given by the regression-line S_1S_2; if $\eta = 0$, it is given by S_3S_4. If both ξ and η have equal standard deviations $\sigma_\xi = \sigma_\eta$, the ideal line is the major axis of the ellipses. The higher the numerical value of r, the more these various lines approach each other, and the less uncertainty exists about the ideal line. The "relative exaggeration of the selected main pulse" is, then, simply the fact that, for instance, the abscissa of S_1 surpasses its ordinate in the ratio $(\sigma_x/r\sigma_y)$.

Another direct way of explaining the phenomenon is the following:

Consider x and y in weak correlation, $x = (ay + \Delta x)$, with $\sigma(\Delta x)$ nearly as great as $\sigma(x)$. Then the selection of pulses in x will in many cases be governed by the "errors" Δx, which are not correlated to y; therefore, the average coordinated pulse in y will be watered down, so to say, by these cases.

The effect can easily be expressed quantitatively. It depends not only on the rules of selection and on the standard deviations, but also on the distribution-curves. It is especially strong if the residuals have U-shaped distributions, for instance, if ξ and η oscillate, like sine-curves, between high and low values.

(*g*) The comparative weakness of the relation between P and R, exhibited in Experiments 1, 3, 4, and 6, is noteworthy. It throws doubt on the significance of the attempts made in the past to obtain, from experiments similar to Experiment 3, the average time of passage of solar particles from the Sun to the Earth.

Any spurious relation between P and W, by way of S_D, because of the special form of S_D in H at Huancayo, would be expected as a lowering of W for high values of P. This effect, indeed, is discernible in Experiment 3, where the main positive pulse in R, accompanying the selected pulse in P, should, according to Experiments 1 and 2, raise W as well, unless the spurious effect of S_D on A_S would not counterbalance this increase. But even in this extreme case, the spurious effect is slight, proving the separation of W and P to be quite satisfactory.

§ 17. *Demonstration, in individual cases, of the changes of* R, W, *and* P *within solar rotations*

While the statistical proof for the reality of the relationship between R, W, and P has been furnished by the described studies on correlation and by the superposed-epoch method, both having been applied to as much material as possible, it is of interest to see how these relations stand out in individual cases.

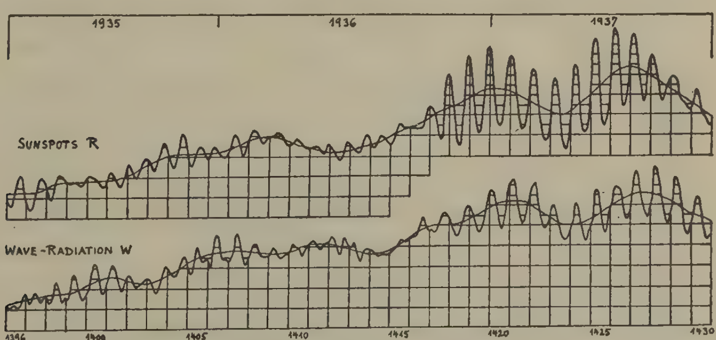

FIG. 3—SLOW VARIATIONS (SMOOTH CURVES) AND SUPERPOSED FAST VARIATIONS IN R AND W DURING RISE OF SOLAR ACTIVITY TO MAXIMUM IN 1937

Figure 3 shows together, in a somewhat idealized diagram, the fast and the slow variations (§ 16*e*) of R and W during the rise of solar activity to the maximum in 1937. The "slow" variations are running quarterly means, and the superposed "fast" variations are the quasi-persistent 27-day periodicities given by smoothed decade-deviations. The relative scales are chosen so that the slow variations, especially the total rise from 1935 to 1937, appear nearly of the same magnitude in R and W. Clearly, the large fast variations, from about Rotation 1417 onward, appear relatively smaller in W than in R, except late in 1937. However, the argument considered in § 16*e* that the slow variations of R are, near sunspot-maximum, likewise

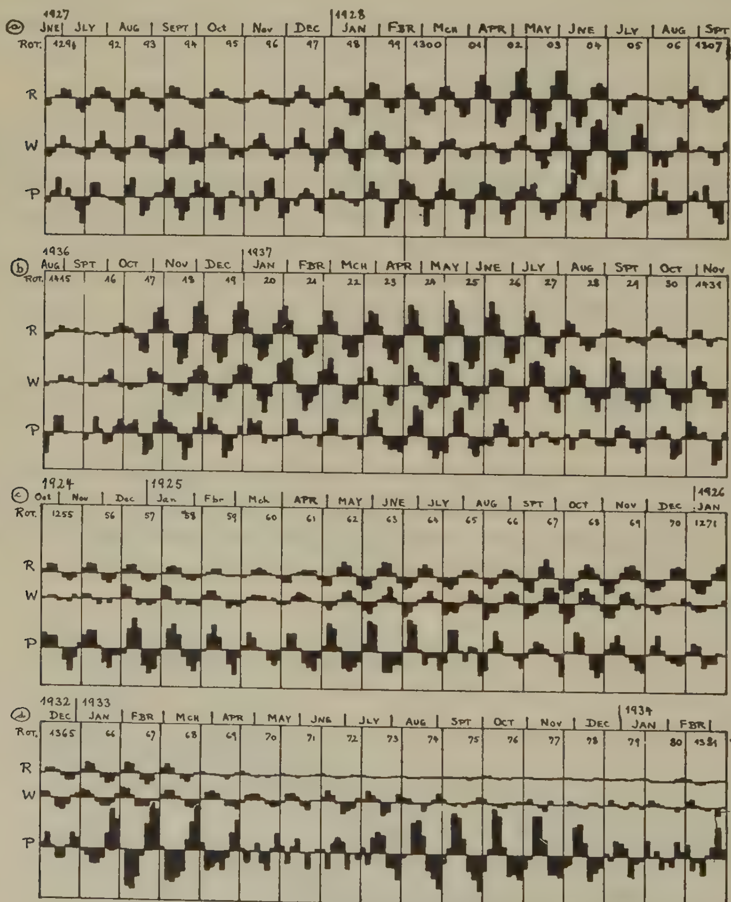

FIG. 4—QUASI-PERSISTENT 27-DAY PERIODICITIES IN R, W, AND P, SHOWN IN SMOOTHED DECADE-DEVIATIONS FOR FOUR INTERVALS: ⓐ AND ⓑ ABOUT THE SUNSPOT-MAXIMA 1928 AND 1937; ⓒ IN 1925; ⓓ IN THE SUNSPOT-MINIMUM 1933 (SCALES: THE VERTICAL DISTANCE OF SUCCESSIVE ZERO-LINES FOR W AND P CORRESPONDS IN R TO 67 UNITS OF ZÜRICH SUNSPOT-NUMBER R; IN W TO ABOUT 27 PER CENT OF THE AVERAGE DAILY AMPLITUDE $A_{S,R=50}$ OF H AT HUANCAYO; IN P TO ABOUT 0.4 UNIT OF INTERNATIONAL CHARACTER-FIGURE C_{INT}

less effective on W, is also well demonstrated. For, while the difference of the levels early in 1935 and in 1937 is about equal in R and W, the slow waves, with maxima at the beginning and in the middle of 1937, appear smaller in W than in R, just as the fast variations.

Figure 4 demonstrates the relations between R, W, and P in the smoothed decade-deviations for typical parts of the whole series. Figures 4*a* and 4*b* show times about the sunspot-maxima 1928 and 1937: The agreement between the *signs* of the deviations in R and W is quite striking, while the *ratio* of the oscillations seems to vary. Figure 4*c* shows the year 1925: Well-developed, long sequences of 27-day recurrences appear in all three phenomena, but while they are parallel in R and W, the maxima in P coincide, in the middle of the year, with the minima in R and W. Figure 4*d* gives the sunspot-minimum year 1933: Small oscillations, parallel in R and W, at the beginning of the year, later disappear completely in R, like the spots themselves, while in W small irregular, probably spurious jags remain. In sharp contrast, P shows those large quasi-persistent periodicities typical for the last part of each solar cycle.

§ 18. *Experiments with daily values*

The curves in Figure 1 were smoothed in order to set forth the main relations. This process tends, however, to hide other characteristic features. Therefore, some of the selected curves were recalculated, using the same epochs, but *daily* values; the gaps in δW_2 could be interpolated. The unsmoothed average lines are reproduced in Figure 5.

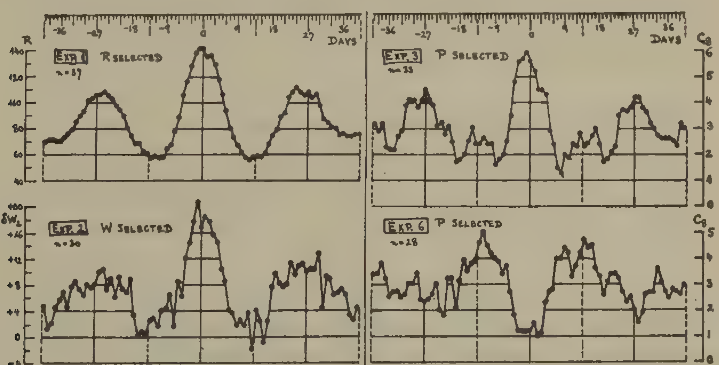

FIG. 5—UNSMOOTHED DAY-BY-DAY VALUES, SELECTED CURVES FOR R N EXPERIMENT 1, FOR W IN EXPERIMENT 2, AND FOR P IN EXPERIMENTS 3 AND 6

Because of the small number of cases combined, the different degree of smoothness (conservation) in the individual cases betrays itself in the more or less jagged appearance of the average curves. Only R shows a smooth curve; but in order to flatten the irregularities in the W- and P-curves to the same level as in R, about 100 times as much observational

material would be necessary. The individual jags in P are due to actual variations of the particle-radiation—but in W they seem partly to reflect the imperfections of the measurement—and of the elimination of L. If R, W, and P are considered as the sums of contributions made by each elementary area on the Sun's surface, they appear as averages over about a hemisphere, but with different weight-functions (Randverdunklung) depending mainly on the distance of the area from the center of the disk.

§ 19. *Experiments* 7 *to* 20

The technique of selecting and smoothing was similar to that used in Experiments 1 to 6 (Figure 1). Experiments 7 to 12 (Figure 6) repeat and

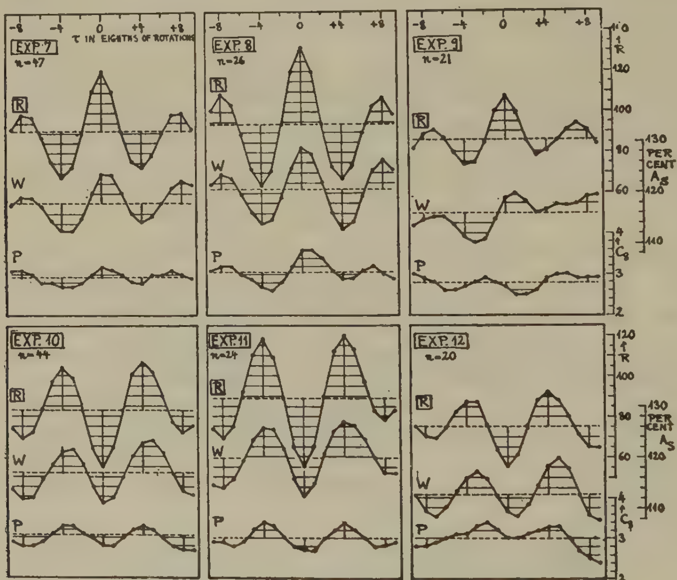

FIG. 6—RESULTS OF SUPERPOSED-EPOCH METHOD FOR EXPERIMENTS 7 TO 12, SELECTED PULSES IN R, POSITIVE (UPPER ROW), AND NEGATIVE (LOWER ROW); WHOLE MATERIAL OF EXPERIMENTS 7 AND 10 IS DIVIDED INTO CASES WITH LARGER PULSES (EXPERIMENTS 8 AND 11) AND SMALLER PULSES (EXPERIMENTS 9 AND 12)

amplify Experiments 1 and 4, although, in the progress of the work, they were made before those. They select positive and negative pulses of R in the eighth-values. Experiments 7 and 10 are similar to 1 and 4, but the results are expressed in actual values, not in deviations, and thereby more illustrative. The similarity of the results of Experiments 1 and 7, and of 4 and 10 removes certain statistical reservations which might have been made regarding the use of deviations in the main experiments.

The material of Experiment 7 was then divided into stronger and weaker pulses in R (Experiments 8 and 9), and Experiment 10 was likewise split up into Experiments 11 and 12. The object was to single out really

great pulses; these are indeed quite imposing in No. 8 and 11. Even here, P remains little affected.

Experiment 13 (Fig. 7) is a precursor of Experiment 2, and a twin experiment to Experiment 8.

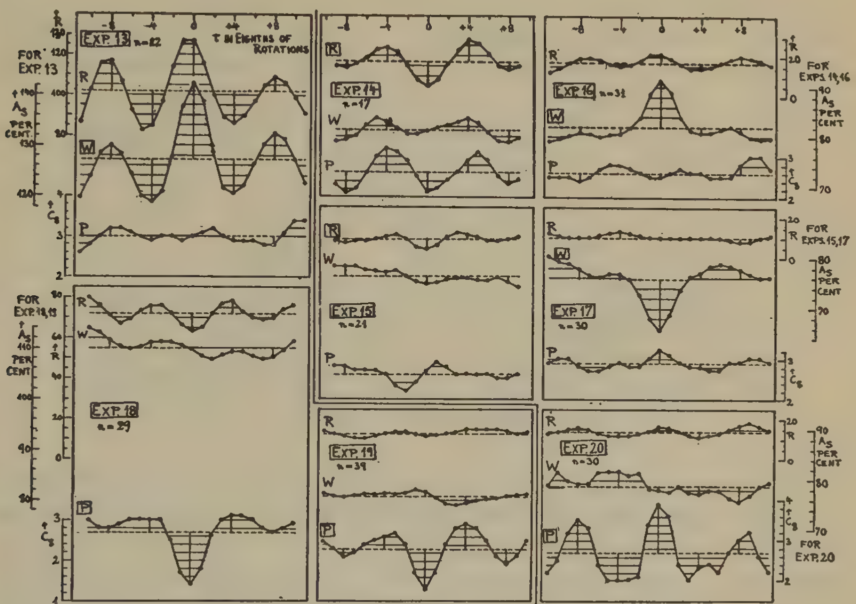

FIG. 7—RESULTS OF SUPERPOSED-EPOCH METHOD FOR EXPERIMENTS 13 TO 20: NO. 13 = POSITIVE PULSES IN $\boxed{W}$, TWIN EXPERIMENT TO NO. 8; NO. 14 = SMALL VALUES OF R NEAR SUNSPOT-MINIMUM CONTRASTING SHARPLY WITH LARGER VALUES ON OPPOSITE HEMISPHERE; NO. 15 = SIMILAR CASES, BUT WITH SMALLER CONTRAST; NOS. 16 AND 17 = PLUS AND MINUS PULSES IN $\boxed{W}$ NEAR SUNSPOT-MINIMUM; NOS. 18 AND 19 = MAGNETIC QUIETNESS (MINUS PULSES IN $\boxed{P}$) NEAR SUNSPOT-MAXIMUM (NO. 18) AND MINIMUM (NO. 19); NO. 20 = MAGNETIC DISTURBANCE (PLUS PULSES IN $\boxed{P}$) NEAR SUNSPOT-MINIMUM, TWIN EXPERIMENT TO NO. 19

Experiments 14 to 17 relate to times of sunspot-minimum: Experiment 14 selects especially small values of R, contrasting with larger values on the opposite hemisphere. There is (Fig. 7) only a small main-pulse effect in W, while P shows a distinct reaction to R. Experiment 15 is a second selection of such cases, but less pretentious; the result, even the selected curve, is rather vague. Experiments 16 and 17 choose high and low values of W in sunspot-minimum; the small response in R throws doubt on the physical significance of these variations of W near minimum, confirming the results of § 6. Again, there is, in Experiment 17, a small response in P to the main negative pulse in W, probably due to a spurious influence by way of S_D in the selected pulses of W (see § 16*g*).

Experiments 18 and 19 study the effect of magnetic quietness (small P selected) near sunspot-maximum (Experiment 18) and near minimum (Experiment 19). The coordinated pulses in R are small, and in W negligible. The same holds for Experiment 20, which can be paired with Experi-

ment 19, and which studies the effect of magnetic disturbance (high P selected) near sunspot-minimum.

§ 20. *Experiments 21 and 22*

Experiments 21 and 22 study, in unsmoothed average lines computed from daily values, the effect of sudden increases or decreases of R in times outside sunspot-minimum (Fig. 8). The irregularities in the curves for

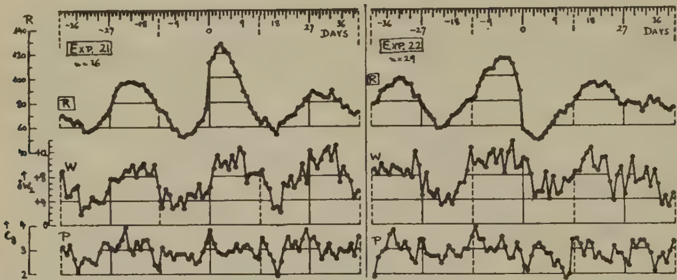

FIG. 8—RESULTS OF THE SUPERPOSED-EPOCH METHOD FOR EXPERIMENTS 21 AND 22: SUDDEN INCREASES OR DECREASES OF R

W and P, due to the small number of cases (see § 18) preclude definite conclusions regarding the simultaneity of the changes in W and P, beyond general trends similar to those found in Experiments 1 and 4. There is a suspicion that the selected steep jumps in R, at least partly, are due to an imperfection in the classical procedure defining R: These numbers are based either on Zürich observations alone, or, if these fail, on an average of the estimates of many other stations reduced to the Zürich standard by reduction-factors; thus, with large values of R, a gap in the Zürich observations might occasionally cause deceptive changes in R from one day to the next. The weak recurrence-tendency of the selected feature would agree with this view. A more detailed experiment should select, as epochs, the appearance or disappearance of spot-groups on the visible disk.

§ 21. *Another form of representation*

The results of the experiments have so far been represented by curves showing R, W, and P as ordinates plotted against time τ. Certain features of the relations between R and W appear, however, more clearly in plots similar to the curves produced by a cathode-ray oscillograph, namely, each pair of simultaneous values of R and W defining a point, R as abscissa, W as ordinate, with time τ, in eighths of rotations, as parameter, written against the dots. Such plots are shown for six typical experiments in Figures 9 and 10.

The narrow, elongated form of the plots indicates that R and W, in these average curves, are nearly, but not completely synchronized. The

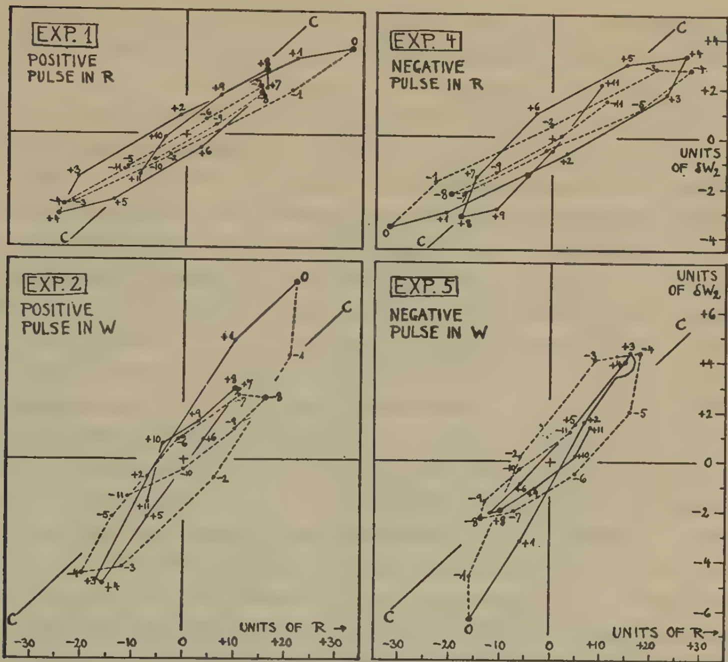

FIG. 9—RESULTS OF EXPERIMENTS 1, 2, 4, AND 5, PLOTTED AS OSCILLOGRAPH-CURVES

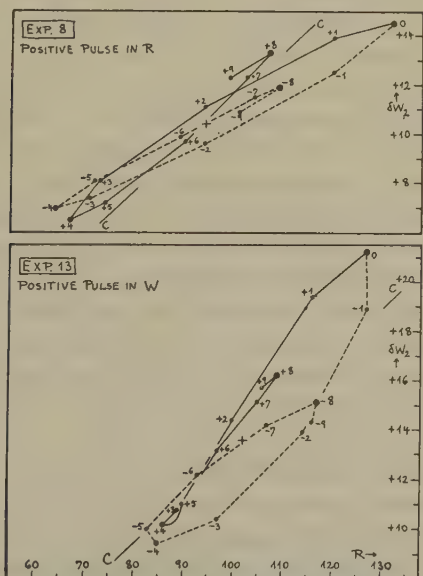

FIG. 10—RESULTS OF THE TWIN EXPERIMENTS 8 AND 13, PLOTTED AS OSCILLOGRAPH-CURVES

characteristic *loops,* described counter-clockwise at the pulses—main ($\tau = 0$), counter ($\tau = -4$ and $+4$), and secondary ($\tau = -8$ and $+8$), signify the lag of W behind R.

The influence of the selection on the average curves can again be demonstrated in these plots, similarly as in § 16*f*. Consider a plane point-cloud representing all simultaneous decade-deviations of R and W. For Experiment 1, a vertical line is drawn cutting off, *toward the right,* a convenient number of selected points with high values of $\Delta_3 R$. The point in Figure 9 marked $\tau = 0$ is the mass-center of these selected points; point $\tau = +1$ is the mass-center of those points following the selected ones after one eighth of a rotation, etc. Now, the point $\tau = 0$ lies on the first regression-line; with normal correlation x, y, its coordinate-ratio (ordinate y to abscissa x) is equal to $(r\sigma_y/\sigma_x)$. In Experiment 2, however, the selected points are those *above* a certain line; point $\tau = 0$ lies therefore on the other regression-line, with the coordinate-ratio equal to $[(1/r)(\sigma_y/\sigma_x)]$. Similarly, in Experiment 4, the selected points lie *to the left* of a vertical line, and, in Experiment 5, *below* a horizontal line. As usual with regression-lines, the points $\tau = 0$ approach the axis of that coordinate which had been selected. This tendency weakens with increasing time-distance from the selected epoch. The secondary pulses (at $\tau = -8$ and $+8$ eighths) therefore hardly show the exaggeration of the selected coordinate, and give a less biased value for the pulse-ratio in R and W.

From Figure 2*a*, the line *CC*, with the equation $\delta W_2 = 0.19\ (R - 50)$, has been entered; it seems to be a fair medium line, the essence of the four experiments taken together.

Figure 10 shows the "oscillograph-curves" for Experiments 8 and 13, which selected specially strong pulses in R and W. The secondary pulses—the loops at $\tau = -8$ and $+8$ eighths—differ from each other; in the recurrent pulse at $\tau = +8$ *following* the main pulse, the effect of R on W is relatively greater than in the pulse at $\tau = -8$ *preceding* the main pulse. This might mean physically that the W-radiation corresponding to a given sunspot-number increases with the age of the spot-groups; the statistical basis for this assumption is, however, not yet very strong. In monthly means, such an effect would appear as a lag of W behind R; this explains perhaps a recent result found by M. Waldmeier in ion-densities in the ionosphere (see § 7).

§ 22. *The physical meaning of* W

The dynamo-theory explains, at least in principle, the observed features of the solar and lunar diurnal magnetic variations, S_q and L, as follows [3]: Atmospheric oscillations (field V of velocities) transverse to the permanent geomagnetic field H induce a field E of electromotive forces. In the conducting regions of the high atmosphere (n ions/cm^3, conductivity κ), E

produces an electric current-system J_e, the magnetic field of which is recorded at the Earth's surface as the exterior part of S_q and L. The time-variations of these exterior currents induce, within the Earth, an interior current-system J_i, which causes the interior part of S_q and L.

Regarding daily periodicities, the vector-fields V, H, and E depend on the geographical coordinates (polar distance and geographic longitude), and on the height z above sea-level. V and H further depend on the season (mean latitude h of the Sun), and on local time of day, t; for L, there are also the variables determining the Moon's orbit, namely, mean longitude of the Moon, of the perigee, and of the ascending node.

H is well known. V is caused partly indirectly—the passive motions of the air on top of the lower atmosphere which oscillates under the action of daily heating and of tidal forces—and partly directly, by the tidal forces and by changes of density and pressure caused *in situ*.

The energy for the ion-production $(\mathrm{d}n/\mathrm{d}t)^{(+)}$ is derived from the absorbed solar wave-radiation, of intensity $W(\lambda)\mathrm{d}\lambda$ for the wave-lengths λ to $(\lambda + \mathrm{d}\lambda)$. Another part of this absorbed radiation is consumed for other processes; of these, dissociation and heating, together with ionization, cause changes in the air-density, and thereby in the pressure-distribution and finally in the field of upper-atmospheric motion, V.

In order to deduce W from the observations of S_q and L, the steps of the dynamo-theory must be made backward: (*a*) Separation of exterior and interior parts of S_q and L, computation of the equivalent outer current-sheet J_e; (*b*) decomposition of J_e according to height z, $\mathsf{J}_e = \int \mathsf{j}_e\,\mathrm{d}z$; (*c*) determination of the field V of atmospheric motion from the observations on pressure-variations and wind; (*d*) computation of the dynamo-field E from V and H; (*e*) computation of the distribution of the conductivity κ from a comparison of the fields E and j_e; (*f*) deduction of the ion-density n from κ; (*g*) estimation of the rate of ion-recombination $(\mathrm{d}n/\mathrm{d}t)^{(-)}$; (*h*) computation of $(\mathrm{d}n/\mathrm{d}t)^{(+)}$ from n and $(\mathrm{d}n/\mathrm{d}t)^{(-)}$; and (*i*) $W(\lambda)$ inferred from $(dn/dt)^{(+)}$.

Of these steps, (*a*) can be based on spherical harmonic analysis of S_q and L after Gauss. Since the Huancayo records have revealed the drastic changes of S_q with the geographic longitude, the older analyses should be repeated for each Greenwich hour separately. Step (*d*) is easy. But all the other steps involve data and theories beyond geomagnetism, namely, astrophysical data on W, results and theories based on the direct methods of ionospheric research, and finally observations and theories on the daily oscillations of the atmosphere. The importance of the study of L, in spite of its smallness, lies in the simplicity of the motion-field V, in which only the effects of the well-known tidal forces must be considered.

When these questions were discussed in Chapters 15 and 23 of "Geomagnetism" [3], it was tested whether the heights of J_e might be identified with one of the ionospheric regions E, $F1$, or $F2$, perhaps differing for S_q

and for L. Since then, it has been shown definitely [5] that, near the equator, J_e L flows *low* in the ionosphere, certainly not as high as the *F*2-layer, but probably in the *E*-layer or below. It is probable, though not quite so certain, that the same holds for the main part of S_q [2].

W is, therefore, probably a solar radiation which is absorbed rather low in the ionosphere, in or near the same layer in which the excessive ultraviolet radiation during a solar eruption causes ionization.

§ 23. *A program for the geomagnetic measurement of* W

While it is not yet feasible to perform the various steps enumerated in § 22, and thus to obtain absolute values for W, this paper has shown the way to deduce time-series for the relative variations of W, that is, to compute a function δW increasing monotonically with W, representing the time-curve for W, so to say, in a transformed scale.

The following ideal program is based on continuous geomagnetic observations, available in the form of hourly means of the force-components, deduced for several sunspot-cycles at a sufficiently close network of stations:

(*a*) The daily periodic variations are freed, as far as possible, from the influence of disturbance, especially of S_D.

(*b*) S_q and L are separated.

(*c*) S_q is separated, by spherical harmonic analysis, into exterior and interior parts; the current-function J_e is computed for each single Greenwich hourly interval.

(*d*) Long-time averages $J_{em}(h, t_0)$ for J_e are computed in order to deduce systematic changes of S_q with season, and with universal time t_0, that is, the change of the current-system J_e in the course of a Greenwich day.

(*e*) Definition of, and calculation of tables for, a scalar quantity expressing the intensity of the current-systems J_e and J_{em}.

(*f*) The ratio of these quantities, for each single hour, to their long-time averages for the same time of day and year (h, t_0) furnishes a measure $W(h, t_0)$ expressed in scales depending on (h, t_0).

(*g*) These scales are standardized, according to the principle of the "assimilation of frequency distributions" [4*a*], to a uniform scale of δW, valid for the whole year.

Of this program, the present paper gives a first step, based on a single observatory.

Further work is handicapped by the scarcity of homogeneous observatory-publications with sufficiently long series, and by the bad distribution of stations over the Globe. Reliable stations in the zone from the equator to about 40° geomagnetic latitude, for which P interferes least with the derivation of W, are few in number; and the many observatories poleward of about 50° latitude are not only more disturbed by ionospheric currents near the auroral zone, but allow an inference on W only in summer, when S_q is large enough.

Daily analyses according to (*a*) to (*d*), therefore, are not practicable for the time being. Instead, individual series of W for selected observatories shall be deduced, to be amalgamated later. The discussion [1] of the characteristic features of S_q indicates, as most suitable for measuring W, the daily amplitudes of the north component X or of the horizontal force H, near the equator, and of the east component Y, or of the declination D, in middle latitudes—D has the advantage that temperature-corrections are not required; if faulty, these might spoil the accuracy of the daily amplitudes of S_q. For Batavia, Honolulu, San Fernando, and Potsdam, daily values of W are being computed; here, much labor is caused by the computation of the influence of L on the daily amplitudes, necessary for its elimination.

Approximate monthly or seasonal means can be obtained from published average daily variations; the inference on W, however, is made somewhat uncertain, in means for "all days," by the influence of S_D, and, in means for the five "international quiet days" per month, by a residual influence of L; for the latter reason, the selection of ten quiet days per month, as practiced by Greenwich and the American observatories, is better.

As a provisional result of a discussion of data from Bombay and Greenwich, it was found that the high sunspot-maximum of 1870.6 (annual mean $R = 140$, compared with the next highest value of $R = 119$ for the last maximum 1937.4) actually brought exceptionally high values of W, expressed in large amplitudes of S_q. This agreement, in turn, corroborates the estimates of R.

Appendix

(A1) *Correlation in absolute values and in deviations*—The variations of R, W, and P have been expressed in many ways: In absolute values such as daily values, eighth-values, monthly, quarterly, and annual means; and in deviations, such as eighth-deviations, decade-deviations, and smoothed decade-deviations. This apparent profusion is made necessary by the different statistical properties accentuating the one or the other feature of these quantities; the choice offered might be useful, it is hoped, in other applications of the numerical data given here.

Tables of averages for rotations have been suppressed in favor of the conventional monthly means, although they would avoid the interference possible in monthly means—a pure 27-day sine-wave of amplitude a causes a fictitious sine-wave of about eight months' period, and of amplitude 0.11 a in monthly means. However, monthly means divide the year conveniently; and the correlations would have differed little.

For R and W, it has been shown in § 5 how the correlation-coefficients r increase with the length of the interval for which the averages are formed; the succession of annual, quarterly, and monthly means discussed there

might have been supplemented by eighth-values and daily values, with r decreasing. The statistical reason has been discussed in the relation (R, P) several years ago [3, § 11.12]; it may be demonstrated here, in another respect, in the 27-day recurrence-tendency of R, in two examples taken from the year 1937 (Fig. 11).

Example I correlates the averages of R for the eighth 1425*a* (abscissa) with 1426*a* (ordinate); 1425*b* with 1426*b*; etc.; finally, 1427*h* with 1428*h*. Example II does the same for the 24 eighths 1431*a* to 1433*h* (abscissas) correlated with 1432*a* to 1434*h* (ordinates). Example III is the superposition of the Examples I and II. In the point-clouds in Figure 11, abscissas and ordinates are always the values which succeed each other after one rotation. The upper row shows absolute values (eighth-*values*) and the lower row shows deviations (eighth-*deviations*). The correlation-coefficients r are written below each cloud.

Examples I and II are chosen for their great difference in the average R, namely, 142 for I, 84 for II.

Obviously, in the superposed point-cloud III, the eighth-*values* give an exaggerated idea of the 27-day recurrence-tendency, because the high correlation $r = +0.64$—which is higher than r in each partial cloud I and II—expressing the elongated form of the point-cloud III, is brought about simply by the superposition of two point-clouds with greatly differing centers. Combination of eighth-values *not* one rotation apart—for instance, 10/8 rotations, combining 1425*a* with 1426*c*, 1425*b* with 1426*d*, etc.—would yield vanishing correlations in clouds I and II, but, in cloud III, nearly as high (but obviously spurious) correlations as for the real 27-day recurrence.

The eighth-*deviations* (lower row in Fig. 11) give a better idea; they show that, in I, there were large deviations with good recurrence, while, in II, the deviations were smaller, and the recurrence-tendency was less obvious. Still, the superposition III gives a fair picture.

The lesson to be drawn refers, of course, to clouds of type III, since ordinarily it would be thought proper to correlate as much material as possible; the splitting of III into I and II reveals, however, the fallacy to which the use of absolute values with high conservation might lead, and the advantage of the use of deviations in such cases.

(A2) *Verification of the scale for* δW_2—A time-series for the intensity of solar wave-radiation derived by a perfect procedure should be expected to show no other systematic annual variation than that caused, geometrically, by the change in the distance between Sun and Earth, namely, an approximate sine-wave, with the highest value at perihelion in the first days of January, exceeding, by about 12 per cent, the smallest value, at aphelion, in the first days of June. And if the energy were to be considered as measured at a constant distance from the Sun, even this sine-wave should disappear. Transition from one conception to the other one is easy. The

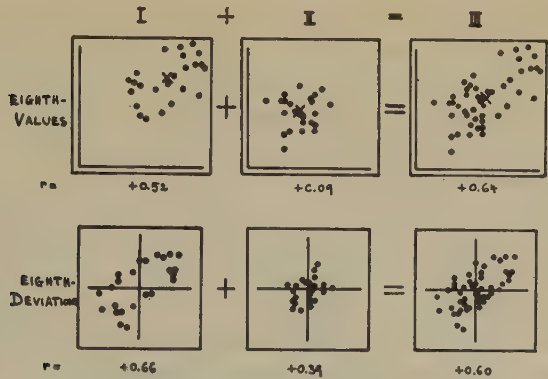

FIG. 11—SUPERPOSITION OF TWO POINT-CLOUDS I AND II; RESULT III FOR ABSOLUTE VALUES (UPPER ROW) AND FOR DEVIATIONS FROM RUNNING AVERAGES (LOWER ROW)

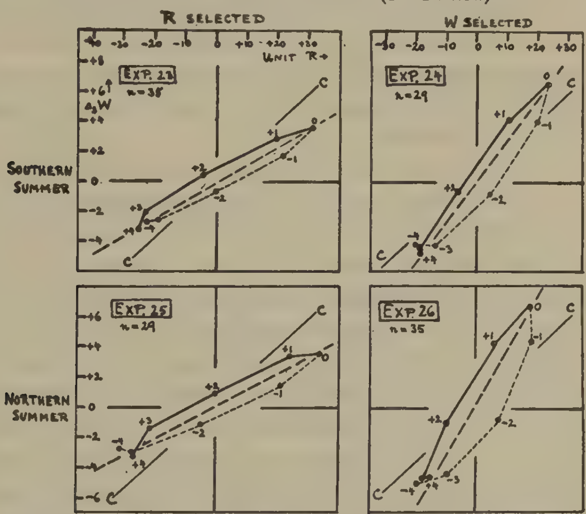

FIG. 12—RESULTS OF EXPERIMENTS 23 TO 26; PULSES SELECTED IN R OR W, SEPARATION IN HALF-YEARS, SOUTHERN AND NORTHERN SUMMER

definitions of δW_1 and δW_2, as deviations from a normal, involve implicitly the absence of a noticeable systematic annual variation.

The computational transition from A_S to δW undergoes, however, such a pronounced seasonal change—reflecting the change of the S_q-current-system from summer to winter—that it seems desirable to verify how far the parameters adopted in Table 2 succeed in furnishing a homogeneous series not only for δW_1 (for which purpose they were defined), but also for δW_2.

In order to test, whether δW_2 is free from a spurious annual variation, Experiments 1, 2, 4, and 5 were repeated, but dividing the year into southern summer (months October to March) and northern summer (months

April to September). The averages of ω_1 in these two half-years are 0.93 and 1.34. In order to obtain a sufficient number of cases, the mean for the plus pulses was combined with the mean for the minus pulses, with signs reversed. So we obtain (Fig. 12) Experiments 23 and 24 (southern summer, pulses selected in R and W), and 25 and 26 (the same for northern summer). Only the main pulses, between -4 and $+4$ eighths, are reproduced in the oscillograph-curves in Figure 12. There is, of course, the contrast, explained in § 16*f*, between Experiments 23 and 25 (selection for R, as in Experiment 1) and Experiments 24 and 26 (selection for W, as in Experiment 2); but no such obvious difference appears between the two half-years.

Numerically, the change of δW_2 corresponding a change of R by one unit, read from the dashed middle lines of the loops, is, in the order of the four experiments, 0.115, 0.272, 0.108, 0.355. In the selections for R, southern summer gives a higher value than northern summer; in the selection for W, the contrary is the case. This shows that there is no great systematic difference between the seasons. The geometric means, for the two kinds of selections, are, for southern summer 0.178, for northern summer 0.196—a difference of roughly ten per cent.

In other words, the sensitivity of δW_2 to changes of R within a solar rotation does not differ much in the two half-years; this indicates that the scale for δW_2 is fairly homogeneous throughout the year. If the computed higher sensitivity in northern summer, about ten per cent, would be entirely conceived as an imperfection in the formulas for δW_2, this could be corrected by correspondingly toning down the seasonal contrast in ω_2.

(A3) *A statistical model for the exaggeration of the selected main pulse*—For an observed perfect sine-wave, the selected epoch-method, selecting positive pulses, would yield, as average line, identically the same sine-wave. Suppose now that, by observational errors, or by other influences not synchronized with the sine-wave, this is distorted by superposed "bulges," scattered at random. As explained in § 16*f*, the selected epochs would then partly differ from the maxima of the sine-wave; the average line, therefore, would become a sine-wave of smaller amplitude, with an "average bulge" exaggerating the main pulse.

As a numerical example note values at equidistant time-intervals, $t = \cdots, -3, -2, -1, 0, +1, +2, +3, \cdots$; a full cycle of the perfect sine-wave X completed in the period 24 time-units. The bulges ξ are single cycles of a negative cosine-wave with the period 8 time-units. On each full cycle of X, one bulge is superposed, at a phase of X chosen at random, and independent for each cycle: $x = X + \xi$; $X = 38 \sin (2\pi/24)(t + 6)$, $\xi = 30[1 - \cos (2\pi/8)(t' + t_k)]$, $t' = 0, +1, +2, \cdots, +8$, $t_k = 24k +$ random integer between -4 and $+20$, and $k = \cdots, -3, -2, -1, 0, +1, +2, +3, \cdots$

The selected epoch-method, positive pulses, yields, as average line,

24 sin $(2\pi/24)(\tau + 6)$ + an average bulge centered at the origin, $\tau = 0$, stretching from $\tau = -8$ to $+8$, and raising the main pulse at the origin by 40 units.

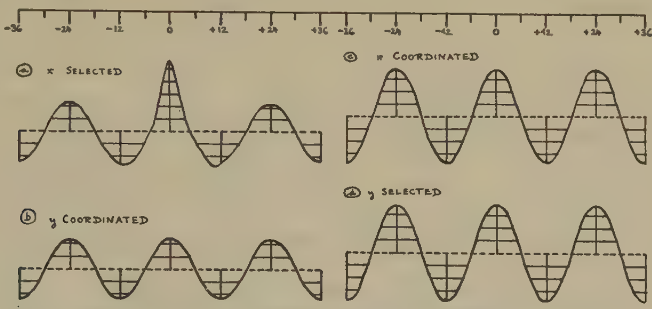

FIG. 13—RESULTS OF TWO EXPERIMENTS AFTER THE SUPERPOSED-EPOCH METHOD APPLIED TO STATISTICAL MODEL FOR EXAGGERATION OF MAIN PULSE; A PURE SINE-WAVE y IS COMPARED WITH FUNCTION x CONSISTING OF SAME SINE-WAVE DEFORMED BY RANDOM BULGES

In deviations from running averages over 24 time-units (Fig. 13*a*), the exaggeration of the main pulse is reduced to 33 units. All recurrent pulses are of equal magnitude as the two drawn in Figure 13*a*.

It is interesting to note that, in curve (*a*), the counter-pulses occur nearer to the main pulse than half a period, just as in Experiments 1 to 6 (see § 16*c*).

If, now, x is compared with a pure sine-wave $y = X$, the selected epoch-method yields: For epochs selected in x, the curve for x given in Figure 13*a*, with exaggerated main pulse, and flattened secondary pulses, and the coordinated curve in y, as in Figure 13*b*, the sine-wave X flattened; for epochs selected in y, both the selected curve in y as the coordinated curve in x are the unaltered sine-wave X (Fig. 13*c* and *d*).

The analogon to our Experiments 1 and 2 is furnished by the model $x = X + \xi$, $y = Y + \eta$, with ξ and η random and uncorrelated bulges; the selected curve will be of the type Figure 13*a*, the coordinated curve of the type Figure 13*b*.

(A4) *Error-limits of the correlation-coefficients*—Some of the values of r have, in § 5, been given to three decimals. This was necessary in order to indicate the relative values of r in such sequences as monthly-quarterly-annual averages, but exaggerates the apparent accuracy of the values.

An idea of the error-limits for r shall be given after R. A. Fisher, who uses the index z, with r = tangens hyperbolica z. With n pairs of data correlated, even for small values of n, the sample-distribution of z is nearly normal, with the square of the mean error $[1/(n - 3)]$. The error-limits were chosen three times the mean error; the chance-probability that these limits are exceeded is only 0.27 per cent. The results, obtained by means of Koller's diagrams [8], are given in the order lower chance-limit $\cdots$ computed value of r $\cdots$ upper chance-limit.

From § 5, $r(\delta W_1, \delta R)$:

monthly averages, $n = 212$	$r = +0.920 \cdots +0.930 \cdots +0.939$
quarterly averages, $n = 70$	$r = +0.960 \cdots +0.969 \cdots +0.979$
annual averages, $n = 18$	$r = +0.980 \cdots +0.988 \cdots +0.992$

From § 5, $r(\delta R, \delta P)$:

monthly averages, $n = 212$	$r = +0.689 \cdots +0.724 \cdots +0.755$
quarterly averages, $n = 70$	$r = +0.825 \cdots +0.860 \cdots +0.889$
annual averages, $n = 18$	$r = +0.905 \cdots +0.942 \cdots +0.965$

From § 6, correlation between monthly changes in δR and δW_1:

Minimum, $n = 106$	$r = -0.03 \cdots +0.07 \cdots +0.17$
Maximum, $n = 105$	$r = +0.34 \cdots +0.42 \cdots +0.50$

Here, as usual, the number n of observed pairs of values has been inserted in the formulas for the error-limits. The author has, however, often emphasized [3, § 16.27, and later in "Law and chance in geophysics," 9], that, in time-series with conservation, the *effective* number n_{eff} of independent observations should be used instead. Thus, in the cases of § 5, n_{eff} will be only a fraction of n, and the error-limits will be correspondingly widened, as discussed in [9]. This question will be treated somewhere else.

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AMERICAN MAGNETIC CHARACTER-FIGURE, C_A, THREE-HOUR-RANGE INDICES, K, AND MEAN K-INDICES, K_A, FOR JANUARY TO MARCH, 1946

BY W. E. SCOTT

Summaries of American *URSI* broadcasts have appeared regularly in this JOURNAL since the issue for December, 1930.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and the United States Coast and Geodetic Survey with the cooperation of the United States Army and the United States

TABLE 1—*American magnetic character-figure C_A for Greenwich half- and full-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for January to March, 1946*

Day	January			February			March		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	0.3	0.4	0.3	0.0	0.1	0.0	1.2	0.2	0.7
2	0.1	0.2	0.1	0.4	0.1	0.2	0.7	0.2	0.5
3	0.9	1.6	1.3	0.1	0.7	0.4	0.0	0.1	0.0
4	1.2	0.7	1.0	0.1	0.5	0.3	0.5	0.7	0.6
5	0.3	0.2	0.2	0.2	0.6	0.4	0.7	0.6	0.6
6	0.1	0.2	0.2	0.1	0.6	0.3	0.4	0.4	0.4
7	0.1	0.3	0.2	1.2	2.0	1.6	0.4	0.1	0.2
8	0.1	0.0	0.1	1.8	1.3	1.5	0.0	0.1	0.1
9	0.0	0.1	0.0	0.3	0.4	0.3	0.1	0.8	0.4
10	0.1	0.4	0.2	0.3	0.3	0.3	1.1	1.3	1.2
11	1.0	0.2	0.6	0.1	0.1	0.1	0.7	0.6	0.7
12	0.4	0.1	0.2	0.0	0.4	0.2	0.1	0.0	0.0
13	0.0	0.0	0.0	0.3	0.2	0.2	0.0	0.1	0.1
14	0.0	0.0	0.0	0.7	0.9	0.8	0.0	0.1	0.1
15	0.0	0.1	0.1	0.8	0.3	0.5	0.2	0.2	0.2
16	0.4	0.2	0.3	0.1	0.5	0.3	0.0	0.2	0.1
17	0.4	0.5	0.4	0.4	0.0	0.2	0.7	0.7	0.7
18	0.2	0.5	0.4	0.1	0.4	0.2	0.2	0.0	0.1
19	0.4	0.1	0.2	0.9	1.0	1.0	0.0	0.2	0.1
20	0.0	0.0	0.0	0.2	0.9	0.5	0.2	0.4	0.3
21	0.0	0.0	0.0	1.2	0.7	1.0	0.5	0.1	0.3
22	0.5	0.1	0.3	0.8	0.4	0.6	0.9	0.9	0.9
23	0.4	0.6	0.5	0.8	0.5	0.6	0.4	0.6	0.5
24	0.8	1.0	0.9	0.1	0.4	0.2	1.6	1.4	1.5
25	0.1	0.4	0.3	0.4	0.1	0.3	1.8	1.9	1.8
26	0.5	0.6	0.5	0.1	0.1	0.1	1.3	0.6	0.9
27	0.1	0.1	0.1	0.0	0.0	0.0	0.6	0.7	0.7
28	0.0	0.0	0.0	0.0	0.1	0.0	2.0	2.0	2.0
29	0.2	0.2	0.2				1.2	0.5	0.9
30	0.0	0.2	0.1				0.0	0.0	0.0
31	0.0	0.1	0.1				0.3	0.4	0.3
Means	0.3	0.3	0.3	0.4	0.5	0.4	0.6	0.5	0.5

Table 2--Three-hour-range indices, K, January to March 1946

January 1946

	1	2	3	4	5	6	7	8
Si	0144 2321	2123 3321	0049 7865	5666 4543	2233 3211	2132 2331	0003 2121	1221 1121
Ch	2233 2232	3212 1210	0147 7645	6554 2445	4431 3213	4232 1322	0200 2132	1211 1120
Tu	2223 2232	3112 1212	1146 6554	5554 3434	3332 2112	3122 2233	1101 2132	1221 1021
SJ	1123 1232	2011 0320	0146 6655	5343 0344	2220 1202	3022 1220	0101 0020	1211 0110
Ho	1023 1122	2002 0110	0044 4643	3343 2322	2212 1121	2110 1122	0001 1011	1100 0011
Hu	2112 3443	2000 3431	0045 8854	4442 2542	2122 2331	2112 2432	1101 2421	1102 2121
Wa	2223 3331	1322 2321	1157 6865	5565 3542	2222 2222	2232 2431	1223 2332	1232 1221
	9	10	11	12	13	14	15	16
Si	0012 1100	0011 1210	1546 3222	1224 3121	0002 2010	0122 0100	0021 0100	1121 3211
Ch	1011 2200	0212 2222	2544 2113	2214 2121	0200 1120	0211 0001	1010 1112	4310 1111
Tu	1112 1111	0222 2211	3554 3113	2223 1112	0100 0111	0211 0001	1121 0112	3321 2102
SJ	0000 2100	0112 2210	1543 1123	2112 0021	0100 0320	0200 0000	1010 1213	3310 0311
Ho	0000 2000	0022 2222	2334 2132	2213 0101	0000 0011	1001 0001	1120 0112	1310 1000
Hu	1111 3310	0123 3432	2433 3333	2112 2231	0000 2320	0101 2221	1011 1322	2322 3321
Wa	1112 2221	1223 3332	2454 3333	2222 2332	2112 2121	2111 1222	1122 1213	2322 3222
	17	18	19	20	21	22	23	24
Si	1353 0132	0134 2322	3222 1011	1210 0000	0000 0011	1553 4001	2144 3134	2255 7432
Ch	2332 1223	0222 2232	4211 1022	2210 0000	0000 0112	2331 2112	3232 2134	4444 4334
Tu	2332 1123	1222 2212	3322 1012	2210 0001	0001 0002	3443 3102	3332 2125	4354 5333
SJ	1221 1233	0112 2332	3212 0111	1100 0000	0000 2111	1221 1102	2131 1114	2233 3333
Ho	1131 0144	0002 1212	2212 1011	1100 0000	1000 0012	2441 3112	2121 1024	2233 4223
Hu	2221 2453	0011 4431	2212 3232	0200 1122	0000 1322	2211 3212	2122 3344	2233 5543
Wa	2443 1343	1222 3433	3333 2132	1212 1111	1111 2122	4242 3212	3333 3223	3343 5533
	25	26	27	28	29	30	31	
Si	2022 3421	2455 3332	1211 1011	1012 2110	0213 3310	1112 1020	0122 2211	
Ch	3321 3222	3443 3331	2211 1111	0012 1011	1312 2111	2111 2131	1221 2212	
Tu	2221 3213	4453 3422	3321 1111	0012 1113	2322 2222	2122 1242	2122 2212	
SJ	2110 1221	1223 1430	1111 0000	0001 0002	1211 2210	2121 0031	1010 1111	
Ho	1000 2212	1232 1220	0110 1011	1012 1012	1311 2111	2122 1022	2112 2212	
Hu	1111 3442	2221 2531	1111 3321	0011 2221	2311 4332	2122 3331	1111 4422	
Wa	2322 4332	2333 3432	2222 1211	1122 1112	2333 3211	2333 3112	1222 2322	

February 1946

	1	2	3	4	5	6	7	8
Si	0101 1101	2232 3110	1011 3233	2113 4322	3422 2322	2000 4232	3249 9968	8888 6733
Ch	1001 1111	3321 1111	0100 4222	1112 3223	2220 2323	3012 3232	2239 8857	8766 5532
Tu	1111 1222	3331 1223	1111 4342	2122 3223	2321 2433	2122 4444	3248 7866	7677 5643
SJ	0101 2211	2221 0000	0000 3222	2110 2222	1000 2223	0001 3111	1037 6547	7555 4331
Ho	0101 1100	2220 1011	0001 4221	1113 1113	0310 1223	1111 3133	1137 5647	7666 4422
Hu	1101 3331	2321 2331	0101 5452	2122 4523	1211 3533	1111 3442	2127 8867	6545 7632
Wa	1212 2212	3343 2112	2332 4333	3143 3323	2221 3334	2232 3123	2237 7867	9767 5532
	9	10	11	12	13	14	15	16
Si	1134 3423	2243 4422	2223 3210	0112 3332	2134 5410	0167 4354	3451 2221	0101 1132
Ch	0044 3223	1343 4222	1222 3110	0211 1223	1144 4310	1154 2454	3541 3221	1001 2233
Tu	1033 2333	2342 4333	2222 3221	1112 2333	3143 3211	1254 2443	3552 3222	2111 2223
SJ	0021 1101	0110 2210	0000 2000	0000 0121	0033 2010	0142 1343	3411 2110	1001 2222
Ho	0122 1112	1131 2211	1111 2110	1001 0113	2022 2100	0254 1333	3442 2122	2111 2233
Hu	0022 3322	0221 3220	1112 3420	0101 3443	1123 4322	0142 3664	3322 3433	1111 4443
Wa	1133 2222	1243 2231	2321 2211	1101 2223	1233 3100	2355 2544	5343 3221	2222 2233
	17	18	19	20	21	22	23	24
Si	2321 0000	1111 0120	2335 3343	2224 2244	5677 7631	3346 2221	2455 4432	1033 3133
Ch	2421 0111	1210 1232	3443 3454	2223 2245	5365 5421	5433 3232	3544 2231	2123 2133
Tu	3430 0001	1111 1323	3544 3444	2223 1235	5465 5423	5434 3322	4544 3333	2133 2143
SJ	2320 0000	1100 0331	3432 2353	1201 1224	4244 5321	4322 3221	1322 2220	0000 0032
Ho	2321 0011	0100 0232	3443 3244	2112 0125	3355 2311	4344 2122	2333 2111	1023 1122
Hu	2210 1211	1111 2442	3443 4664	1201 3454	4233 5532	3322 4432	3332 3331	1111 3343
Wa	3321 1211	2322 2221	4454 3443	2223 1245	5345 6342	4433 2222	3343 4432	1222 2142
	25	26	27	28				
Si	2235 3221	2114 2111	0001 0100	0000 0021				
Ch	3423 2113	2212 1122	0110 0101	1010 1031				
Tu	3334 1112	2223 1122	0100 0202	1121 1131				
SJ	1100 0000	1100 1001	0000 0000	1011 1021				
Ho	2113 1003	0113 1012	0100 0100	0110 0011				
Hu	2322 3331	1212 2321	0002 1320	1112 3331				
Wa	2333 2222	1132 2321	1111 0110	1121 1011				

Table 2--Three-hour-range indices, K, January to March 1946--concluded

March 1946

	1	2	3	4	5	6	7	8
Si	3676 1213	3342 1112	1110 0111	2244 3333	3234 5522	3345 4122	2134 4111	1010 1121
Ch	4544 0123	4433 2112	1120 1121	2243 3235	4333 3233	3233 3123	3223 2111	0100 1141
Tu	4654 1223	5333 2222	2210 1112	3344 2234	4333 3333	3343 3223	2223 2221	1110 1232
SJ	4431 0112	4222 2102	1110 0100	1232 2143	4223 2112	2222 1211	2112 1110	0000 0021
Ho	4553 1212	3223 2122	2210 0011	1223 1122	3222 2321	2233 2112	2113 3111	1200 0022
Hu	4433 2333	3223 4422	2210 2322	2121 4443	3224 4442	2121 3431	2122 2420	0001 2362
Wa	4664 1314	5333 2113	2221 1122	2334 3345	3433 4322	3232 3322	3223 3221	1121 2222
	9	10	11	12	13	14	15	16
Si	1010 2442	4445 6555	4444 5233	1131 1110	0112 1121	1103 1121	1136 5211	0011 2211
Ch	0110 2343	5555 5345	5544 3324	1121 1101	0211 1121	1103 1221	1033 3211	0011 1122
Tu	1111 2443	5444 5464	4443 3335	2222 1110	1212 1121	1103 2121	2034 3223	0021 2223
SJ	0000 1442	4434 3363	4221 2333	1100 0000	0100 0110	0101 1021	0022 1100	0000 0122
Ho	0000 2343	4443 3354	3232 2333	0110 0011	0102 0011	1100 0021	1122 2111	0011 1012
Hu	1002 2662	4333 6553	3222 4533	1110 2221	1111 3332	1101 3331	1022 3322	0011 2332
Wa	1322 3442	5444 4555	5332 3333	2322 1111	2212 2332	1212 2131	3124 2322	0111 3212
	17	18	19	20	21	22	23	24
Si	3333 5331	1134 1111	1131 2022	2114 4222	2235 5110	0274 4223	2210 2224	7758 9934
Ch	5542 3343	3233 2221	1121 1123	3223 3223	3422 2211	0354 3235	3321 2235	7845 6636
Tu	4542 4334	2233 1210	1221 1123	3223 3212	2333 2211	1354 3335	3322 1334	7755 6635
SJ	4521 2433	1022 1210	0010 0123	3212 3212	2421 0100	0344 3335	4311 1324	7634 4434
Ho	3331 3232	2113 1100	0120 1023	3012 2112	2323 1110	0354 3235	4221 0224	7535 5434
Hu	3431 3443	2011 2321	1111 1333	3112 4322	2421 3321	1333 5444	3312 2434	6434 7733
Wa	3433 5443	2123 2221	2221 2123	3223 3222	3323 2111	1354 4224	3222 4336	6546 7743
	25	26	27	28	29	30	31	
Si	7799 9995	5677 5442	3425 4533	5789 9967	5444 4221	2211 1122	1144 4113	
Ch	6677 6777	6564 1242	5423 2335	6589 9987	6543 3233	3201 1122	1233 1114	
Tu	6677 6765	6665 3332	4513 3433	5579 9877	5554 3312	2212 1222	1233 2234	
SJ	5656 7555	6443 0222	5402 1224	4578 9776	6443 2211	2100 1121	0111 0012	
Ho	6346 5655	4455 2221	3303 3322	5479 9876	4343 3212	2012 1121	1133 2024	
Hu	5545 6674	5432 2332	3401 3443	5477 8976	5433 4422	2212 2321	1222 1223	
Wa	6459 6777	4445 3552	3212 4534	4389 9876	5454 3322	1112 1222	2233 3213	

¨Interpolated

Table 3--Weighted average of reduced three-hour-range indices, January to March 1946

Day	January 1946									February 1946									March 1946								
	Values K_A								Sum	Values K_A								Sum	Values K_A								Sum
1	1^x	2	2^x	3	2	2^x	3	2	18^x	0^x	1^x	0^x	1	1^x	2	1	1^x	9^x	4	5	4^x	3^x	1	2	1^x	3	24^x
2	2^x	1^x	1^x	1^x	1^x	2^x	1^x	1	13^x	3	3	3	1^x	1^x	1	1	1	15	4	3	3	2^x	2	1^x	1	2^x	19^x
3	0^x	0^x	4^x	7	6	6^x	5	5	35	1	1	1	1	3^x	2^x	3	2^x	15^x	1^x	1^x	1^x	0	0^x	1	1	1^x	8^x
4	5^x	5	5	4	2	4	3^x	3^x	32^x	2^x	1^x	2	2	2^x	2^x	2	3	18	2	2^x	3	3	3	2^x	3	4	23
5	3	2^x	2^x	1^x	2	2	1^x	2	17	2	2^x	1^x	0^x	2	3	2^x	3	17	3^x	3	3	3	3^x	3	2^x	2^x	24
6	3	1^x	2^x	2	1^x	2^x	2^x	1^x	17	2	1	1^x	1^x	3	2	3	2^x	16^x	3	2^x	3	2^x	3	2	1^x	2	19^x
7	0^x	1^x	0^x	1^x	1^x	1^x	2^x	1^x	11	2^x	2	3^x	8	7^x	7^x	5^x	7	43^x	2^x	1^x	2	3	2^x	2	1	1	15^x
8	1^x	2	1^x	1^x	1	1	2	1	11^x	8	7	6^x	6^x	5	5	3	2^x	43^x	1	1	0^x	0^x	1	1^x	3	1^x	10
9	0^x	0^x	1	1	1^x	1^x	0^x	0^x	7	0^x	1	3	3	2	2^x	2	2^x	16^x	0^x	1	1	1	2^x	4	4^x	2^x	17
10	0	1^x	1^x	2	2	2^x	2	1^x	13	1^x	2^x	3^x	2	3	2^x	2	1^x	18^x	4^x	4	4	4	4^x	4	5	4^x	34^x
11	2	5	4^x	4	2	2	2	3	24^x	2	2	1^x	1^x	2^x	2	1	0^x	13	4^x	3^x	3	2^x	3	3	2^x	3^x	25^x
12	2^x	2	1^x	3	1^x	1^x	2	1^x	15^x	0^x	1^x	0^x	1	1^x	2^x	2^x	3	13	1^x	1^x	2	1	1	1	0^x	0^x	9
13	0^x	1	0	0^x	1	1	1^x	0^x	6	1^x	1^x	3	3	3	2	1	0^x	15^x	0^x	1^x	1	1^x	1	1^x	2	1^x	10^x
14	0^x	1^x	1	1	0^x	1	0^x	1	7	1	2	5	4^x	2	3^x	4^x	4	26^x	1	1^x	0	2	1^x	1^x	2	1	10^x
15	1	0^x	1^x	1	0^x	1^x	1	2	9	4	4^x	4	2	2^x	2	2	1^x	22^x	1^x	0^x	2^x	3^x	3	2	1	1^x	15^x
16	3	3	2	1	2	1^x	1	1^x	15	1^x	1^x	1	1	2	2	3	3	15	0	0	1	1	2	1^x	1^x	2	9
17	2	3	3^x	2	1	2	3	3	19^x	3	3^x	2	0^x	0	1	0^x	0^x	11	3^x	4	3	2	3^x	3^x	3^x	3	26
18	0^x	1^x	2	2	2	3	2^x	2^x	16	1^x	2	1	1	1	2^x	2^x	1^x	13	2	1^x	2^x	3	1^x	2	1	0^x	14
19	3^x	2^x	2	2	1^x	0^x	2	2	16	3^x	4	4	3^x	2^x	3^x	4^x	4	29^x	1	1^x	2	1	1^x	1	2	3	13
20	1^x	2	0^x	0^x	0	0	0^x	0^x	5^x	2	2^x	1^x	2^x	1^x	2	3^x	5	20^x	3	1^x	1^x	3	3	2	1^x	2	17^x
21	0^x	0	0	0^x	0^x	1	1	2	5^x	5	3^x	5^x	5	5	3^x	2^x	1^x	31^x	2^x	3^x	2^x	2^x	2^x	1^x	1	0^x	16^x
22	2^x	3^x	3^x	1^x	2^x	1	0^x	2	17	4^x	3^x	3	3^x	2^x	2^x	2^x	2	24	0^x	3	5	4	3^x	2^x	2^x	4^x	25^x
23	3	2	3	2^x	2	1^x	2^x	4	20^x	3	4	4	3^x	2^x	3	2^x	1^x	24	3	2^x	1^x	1^x	2	3	2^x	5	21
24	3^x	3	4	3^x	4^x	3^x	3	3	28	1^x	1	2	2	2	1^x	3^x	2^x	16	6^x	6	3^x	5^x	6^x	6^x	3	4^x	42
25	2^x	1^x	1^x	1	2^x	2^x	2	2	15^x	2^x	3	2	3	1^x	1^x	1^x	2	17	6	5	6^x	7^x	6^x	7	7	6	51^x
26	2^x	3^x	3^x	3	2	3	3	1^x	22	1^x	1^x	1^x	2^x	1^x	1^x	1^x	1^x	13	5	4^x	5	4^x	2	3^x	3^x	2	30
27	2	2	1^x	1	1	1	1	1	10^x	0	0^x	0^x	0^x	0	1^x	0^x	0^x	4	4	3^x	1	2^x	3	4	3	4	25
28	1	0	1	1^x	1	0^x	1	1^x	7^x	1	0^x	1	0^x	1	0^x	2	1	7^x	5	4^x	7^x	9	9	8^x	7	6^x	57
29	1^x	3	1^x	2	2	2	1^x	1	14^x										5	4	4	3^x	3	2^x	1^x	2	25^x
30	2^x	2	2	2	1^x	1	2^x	1	14^x										2	1^x	1	1^x	1	1^x	2	1^x	12
31	1	1^x	2	1^x	2	2^x	1^x	2	14										1^x	2	3	3	2	1^x	1^x	3^x	18

Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and its values for the first twelve, the second twelve, and all twenty-four hours of each Greenwich day for January to March 1946, are given in Table 1.

The three-hour-range indices, K, have been compiled since April 6, 1940, for each of the seven American-operated observatories. The eight indices for each day give geomagnetic activity for three-hour periods successively during the Greenwich day. The indices range from "zero" very quiet to "nine" extremely disturbed. The K-indices for Sitka (Si), Cheltenham (Ch), Tucson (Tu), San Juan (SJ), Honolulu (Ho), Huancayo (Hu), and Watheroo (Wa), for January to March 1946, are given in Table 2. Interpolated indices are shown thus, $\ddot{3}$.

In the manner set forth in the JOURNAL for September, 1940, the indices are standardized into reduced indices K_r to eliminate local variations. A weighted mean index K_A, is derived from the reduced indices. The reduced indices from Si, Ch, and Wa are given double weight and those from Tu, SJ, Ho, and Hu are given single weight. The weighted indices, K_A, for January to March, 1946, are given in Table 3. A superior cross ($^{\times}$) following an index-number denotes a half-unit, thus $5^{\times} = 5.5$, etc.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington 15, D. C., April 30, 1946

THE APPLICATION OF SOLAR AND GEOMAGNETIC DATA TO SHORT-TERM FORECASTS OF IONOSPHERIC CONDITIONS*.

By A. H. Shapley

Abstract—The program for the systematic collection of current solar and geomagnetic data coordinated at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (DTM CIW), particularly for application to short-term forecasting of magnetic and ionospheric disturbances, has been in progress since July, 1942. The ways in which recurrence-tendencies of geomagnetic activity, reports of solar activity, and various solar-terrestrial relationships are used in preparing the forecasts are described in this report. The forecasts issued by the Interservice Radio Propagation Laboratory (IRPL) in collaboration with DTM CIW are compared with magnetic activity for a 15-month period and show that the forecasts are satisfactory about 70 per cent of the time. The correlation-analyses of coronagraphic and spectroheliographic data with magnetic activity show that over a period of two years there was a decided tendency for disturbances to occur when solar regions identified by these observations were east of the central meridian of the Sun. Reductions of solar and geomagnetic data indicate that a minimum in solar activity occurred early in 1944, but that the minimum epoch of geomagnetic activity cannot as yet be defined. Reference is made to the application of visually recording magnetographs developed at DTM CIW.

Introduction

A concerted attack upon the problem of correlating geomagnetic and solar activity was initiated in July, 1942, under sponsorship of the National Defense Research Committee (NDRC), and has continued since July, 1943, under sponsorship of the Wave Propagation Committee (WPC) of the Combined Communications Board. The objective of the program has been to provide basic data on which short-term forecasts of radio-propagation conditions could be based and on which analyses to improve forecasting techniques could be made. With the cooperation of major solar observatories and agencies making observations of various geomagnetic phenomena, arrangements were made for the prompt reporting of current data to DTM CIW.

The coordinating office has had an unusually complete record of day-to-day solar activity in all of its observable aspects and also very complete information on geomagnetic activity. Summary reports by telephone, telegraph, and radio communication provided a detailed picture of solar and geomagnetic conditions within a few hours. All the data received at DTM CIW are made available to IRPL, where independent evaluation and analysis with respect to radio propagation are conducted.

*This paper is a part of a summary report of April 30, 1945, on a program initiated and accomplished through the cooperation and support of the Navy Department.

Sources of data

Regular reports of solar observations are received daily, weather permitting, from the United States Naval Observatory, the McMath-Hulbert Observatory of the University of Michigan, the Mount Wilson Observatory, and the Fremont Pass Station at Climax (Colorado) of the Harvard College Observatory. Monthly summaries of observations are received from the John Payson Williston Observatory of Mount Holyoke College, from H. H. Clayton of Canton, Massachusetts, and from Neal J. Heines of Patterson, New Jersey.

The United States Naval Observatory reports positions and areas of sunspots derived from its daily photoheliogram. Since May 27, 1944, that Observatory has contributed free-hand drawings of phenomena seen with a Hale spectrohelioscope, which was installed for the purposes of this program. The proximity of the Naval Observatory to the coordinating office makes these observations unusually useful for the evaluation of current solar activity.

The McMath-Hulbert Observatory reports telegraphically the position, area, and intensity of regions of bright calcium flocculi or plages, observed with a spectroheliograph, and estimates of the activity of each region as observed with a Hale spectrohelioscope. Position and area of sunspots are also reported. The Observatory's mail report comprises diagrams of these phenomena and also the location and area of prominences observed in calcium light.

The Mount Wilson Observatory sends a daily telegram reporting the position, area, and estimated activity of sunspot-regions. Magnetic polarities of individual sunspots and drawings of calcium plages are added in a report sent by air-mail.

Up to the spring of 1944, telegraphic reports of coronagraphic observations from Climax included the maximum intensity of the corona and the total area of the prominences observed on each limb on each clear day. Since the spring of 1944, the maximum intensity and position-angle of each region of intense coronal emission have been reported in the telegram, and the daily prominence reports discontinued. Detailed reports of all observations, including sunspots and faculae, and photographic prints of the daily survey of prominences are sent by air-mail.

The arrangements with the principal contributors of solar data make it possible for the coordinating office at DTM CIW and the short-term forecasting section of IRPL to have current information of solar activity a few hours after observation. The three observatories making daily reports of sunspots are widely distributed geographically, so that the number of days is negligible on which reports of sunspots are not received. During the winter observing conditions are less favorable and there are frequently long gaps between successive spectroheliographic or coronal reports, impairing both the immediate application and subsequent analysis.

From Mount Holyoke College are received monthly summaries of the number of sunspot-groups and individual spots observed. These reports, together with similar ones sent by Mr. Heines and Mr. Clayton, are used in compiling preliminary sunspot-numbers.

The magnetic data available to the program include reports of magnetic activity from the stations of the United States Coast and Geodetic Survey (USCGS) at Cheltenham (Maryland), Tucson (Arizona), Sitka (Alaska), Honolulu (Hawaii), and San Juan (Puerto Rico), and from the magnetic observatories of DTM CIW at Watheroo (Western Australia), Huancayo (Peru), and College (Alaska). In addition, K-indices are available from the Toolangi Observatory in Australia, the Godhavn and Ivigtut Observatories in Greenland, and the Clyde Observatory in Baffin Island. Daily and special reports of magnetic activity are reported by the Cheltenham Magnetic Observatory of USCGS and by the Sterling (Virginia) laboratory of IRPL.

Ionospheric data are available from the various stations in the world-wide network operating under the sponsorship of WPC of the Joint Communications Board. Ratings of conditions on commercial radio circuits are furnished at intervals by the Bell Telephone Laboratories and by RCA Communications. Other ionospheric and transmission-disturbance information is supplied by IRPL.

Auroral data from northern United States and southern Canada are systematically furnished through the cooperation of Dr. C. W. Gartlein of Cornell University under a program financed in part by the National Geographic Society. The formulation of auroral data by Dr. Gartlein into auroral-activity indices on a scale similar to the magnetic K-indices has increased their usefulness in evaluation of disturbance.

Method of preparing short-term forecasts

Short-term forecasts of geomagnetic disturbances affecting transmission of radio waves via the ionosphere were issued regularly from March, 1942, until October, 1942, by DTM CIW, and have been issued by IRPL from October, 1942, with the collaboration of DTM CIW. These forecasts originally were prepared weekly for a period four to ten days in advance. Since January 16, 1945, they have been issued semi-weekly for periods three to five and three to six days in advance.

The short-term forecasts are based primarily upon two general considerations: (1) The geomagnetic activity 27 days before the forecast-period and (2) an estimate of disturbance based on the location and degree of activity of solar regions during the period covered by the forecast.

The recurrence-tendency is given high weight when the pattern of magnetic activity during the previous few solar rotation cycles has shown the tendency especially clearly. Figure 1 is a chart arranged to show 27-day recurrence-tendency of magnetic disturbance beginning in June, 1942. The hatched squares indicate days with magnetic character greater than

the mean for the period shown. From March, 1943, to May, 1944, for example, there is a very pronounced recurrence-sequence. At such times, recurrence-tendency is the most important factor in estimating the time of expected disturbance. When the tendency is not clearly shown, such as in the last half of 1944, magnetic activity 27 days previously is taken only as the framework on which estimates are made for the forecast-period.

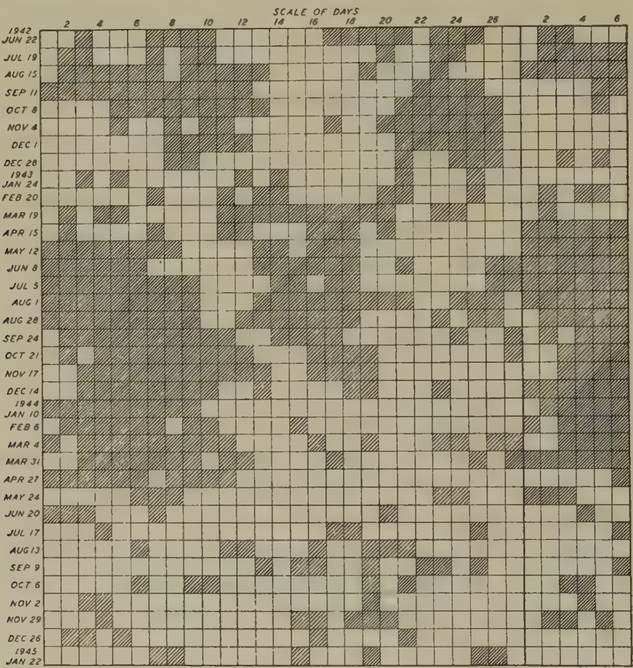


FIG 1—RECURRENCE-TENDENCIES OF MAGNETIC ACTIVITY AT 27-DAY INTERVALS, JUNE 22, 1942, TO FEBRUARY 23, 1945 (SHADED SQUARES INDICATE DAYS ON WHICH MAGNETIC ACTIVITY WAS GREATER THAN MEAN FOR WHOLE PERIOD; DATES REFER TO FIRST DAY OF CYCLE)

When forecasts are issued weekly for period four to ten days in advance, the solar region which will be on the central meridian during the last two days of the period will not have appeared on the east limb at the time the forecast is prepared. If disturbances occur when active regions are east of the meridian, as has been the tendency in the last two years, then the data on which weekly forecasts are based are two or three weeks old, relating to regions during their appearance, if any, during the previous solar rotation. Solar activity developing on the invisible disk can be included consistently only in forecasts for periods shorter than a week. Up-to-date solar data have been used in the daily disturbance warning-service, and recently in the short-term forecasts prepared on a semi-weekly basis.

The solar reports from the various observatories are used to identify regions that may be associated with geomagnetic disturbance. The position

on the solar disk and amount of activity in such regions are the most important criteria for forecasting disturbances from solar data.

A potentially active solar region is characterized by large intense calcium plages, by intense coronal emission, and sometimes by high-speed dark hydrogen filaments and by sunspots. In general, it has been found that the probability of geomagnetic disturbance occurring during the passage of such a region across the solar disk is greater, the nearer it passes to the center of the disk. Rapid growth or large observed velocities within a region and changes in its appearance on the disk from one day to the next are indicators of activity. For persistent regions, the drift in longitude of the center of gravity is taken into account in estimating the time of recurrence.

The date of appearance on the east limb and of central meridian passage of each potentially active solar region known or expected to be on the visible hemisphere of the Sun during the forecast-period is estimated from the solar data available up to the time the forecast is issued. From these dates, the statistical relationships of geomagnetic disturbance and intense coronal-emission regions, large plages, or large sunspots are applied. In the case of persistent regions, the relationship that applied during previous appearances on the disk is used whenever possible, with whatever correction is necessary due to drift in longitude. Geomagnetic activity which normally would not be considered significant will at times indicate the nature of the relationship in individual cases.

The estimates of time of disturbance based on solar data are reconciled with the 27-day recurrence-data to form the final forecast. Subjective weighting is applied when the two disagree. The severity of disturbance indicated in the forecast is based on the general level of geomagnetic activity obtaining at the time.

In addition to the weekly (now semi-weekly) short-term forecasts, disturbance-warnings are issued daily by IRPL covering the ensuing 24-hour period. Warnings are issued when disturbed conditions are in progress or when a disturbance seems imminent as indicated by up-to-date solar and geomagnetic reports. In this way the short-term forecasts may be revised if the course of solar or geomagnetic activity so indicates. Thus a warning, if not always a forecast of disturbed conditions, can be issued for disturbances that commence at approximately the same time as the outbreak of new regions of activity on the Sun. This warning service takes the place of special forecasts which would otherwise be required in such instances.

Evaluation of short-term forecasts of ionospheric disturbance

Many factors must be considered in making a fair judgment of the accuracy of short-term forecasts of ionospheric disturbance and conditions of radio propagation. The problem is three-fold, involving (*a*) the accuracy with which the ionospheric forecasts predict ionospheric disturbances,

(b) the accuracy with which forecasts of radio propagation predict radio-propagation disturbances, and (c) the relation between ionospheric and radio-propagation disturbances.

It is well known that abnormal conditions in the ionosphere affect the performance of different radio circuits at the same time in various ways, depending on the path, frequency, and power used. The result is not necessarily poor propagation-condition. Radio propagation by means of sporadic E-layer ionization is well known. A shift in the geographical location of zones of high ionospheric absorption may result in improvement in the performance of circuits which pass through the normal position of this zone. The task of evaluating the forecasts is made more difficult by non-uniformity in the reporting of radio-circuit performance and uncontrollable variables such as the competence of operating personnel and the efficiency of their equipment. All of these factors complicate the use, in the evaluation of short-term forecasts, of field-reports of conditions of radio traffic.

It is rare to find good agreement among the reports of the performance of even a large number of radio circuits, except in the case of the very few major ionospheric storms. The percentage agreement of a large number of such indicators combined on a daily basis would be an index of the average world-wide disturbance on any given day. This investigation is now under way at IRPL, and will, when completed, afford an evaluation of the short-term forecasts of radio disturbances.

The forecasting of propagation-conditions is based upon the relations between abnormal or disturbed ionospheric conditions and the degree of efficiency of communication-circuits. The forecasts depend basically upon estimates of the degree of normality of the ionosphere on a given day. Like circuit disturbances, ionospheric disturbances are manifested in various ways that may not be consistent on a world-wide or even on a relatively localized scale. In general, ionospheric disturbance of some kind occurs coincidentally with large geomagnetic activity. However, there is some tendency for the return of the ionosphere to normal after a severe storm to be delayed beyond the end of the magnetic disturbance. The coefficient of linear correlation between magnetic and ionospheric indicators of disturbance was significant in each of a series of comparisons based on data for 1943. For daily mean K-index at College, Alaska, compared with the College ionospheric disturbance-ratings, $r = +0.61 \pm 0.03$; compared with the average minimum frequency observed at vertical incidence at College, $r = +0.73 \pm 0.02$; compared with the occurrence-frequency of complete fadeouts and Es above 4 Mc/sec limiting-frequency, $r = +0.86 \pm 0.02$. The correlation between indicators of ionospheric disturbance is in every case lower than between magnetic and ionospheric disturbance-indices. The College ionospheric disturbance-rating and occurrence-frequency of fadeouts and values of Es give $r = +0.70 \pm 0.03$, the largest correlation-

coefficient obtained from a number of comparisons of ionospheric and circuit disturbance-indicators, including field-intensity of a London-College circuit and North Atlantic disturbance-ratings of circuits operated by RCA Communications and by Bell Telephone Laboratories. The methods of ranking ionospheric disturbance are at present imperfect, yet the correlation in some cases is quite satisfactory. However, inasmuch as no worldwide order of ionospheric disturbance is as yet available, the evaluation of the short-term forecasts will, in this paper, be made with reference to magnetic character-figures.

One of the geomagnetic indices of disturbance regularly compiled from the reports of seven American-operated magnetic observatories, including an equatorial station and a station in the Southern Hemisphere, is the American magnetic character-figure, C_A, given for each Greenwich half-day to the nearest tenth on a scale of 0 (quiet) to 2 (disturbed). It is based on a subjective estimate of the disturbed character of the magnetograms (continuous photographic record of geomagnetic conditions) during the whole interval. For convenience, ten times the sum of the half-day character-figures, designated by the symbol $20C_A$, is used as a daily index of geomagnetic disturbance, this being on a scale of 0 to 40. The mean of this character-figure during July, 1942, through December, 1944, is 8.04. The lower limit for disturbed days has been set arbitrarily at 9, and for severely disturbed days at 15. Ionospheric storms are almost always associated with the latter; some ionospheric disturbance usually occurs at the same time as the former. In the above period, which begins with the commencement of the coordinated solar program, 23 per cent of all days were by this definition severely disturbed. When days with character-figures 9 to 14 are included, then 40 per cent of days have the designation disturbed.

A comparison of the half-daily American magnetic character-figure and the sum of the three-hour K_A-indices of magnetic activity for each half-day in the period July, 1942, to October, 1943, gives the correlation-table shown in Figure 2. The coefficient of linear correlation, r, is $+0.952 \pm 0.002$, and the lines of regression are as shown. The lower limits selected for ranges of disturbance on the scale of $20C_A$ correspond to mean K_A of about 2.4 and 3.1, respectively. These two indicators of magnetic activity may be used interchangeably in correlations with other geomagnetic and solar data without appreciable error.

In making an evaluation of the reliability of the short-term forecasts, the A-zone radio-propagation condition-ratings, as issued in the forecasts of IRPL, have been used for the period since numerical ratings, ranging from 1 ("useless") to 9 ("excellent"), were first used. The A-zone forecast, applicable to high terrestrial latitudes, is subject to the greatest variation, since auroral-zone propagation-conditions are most sensitive to ionospheric disturbance. There are some slight differences in preliminary forecast-rat-

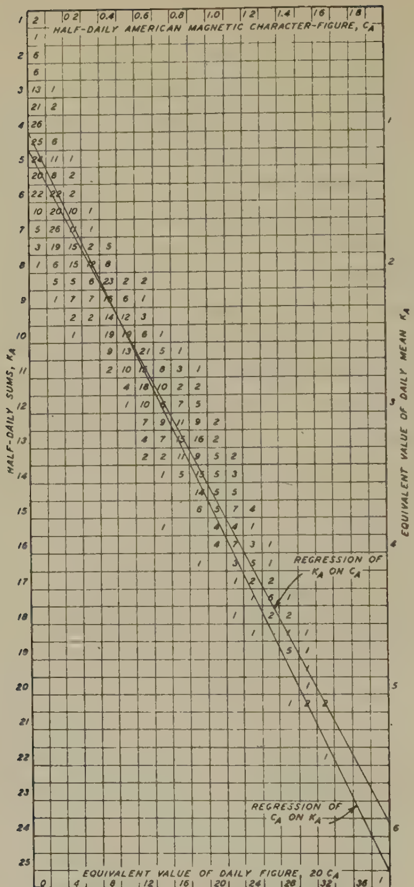
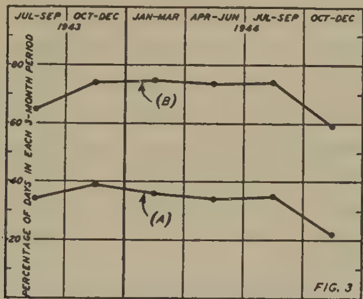


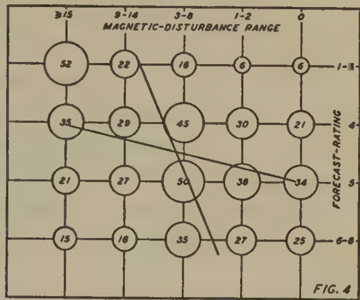
FIG. 2—CORRELATION-TABLE OF HALF-DAILY AMERICAN MAGNETIC CHARACTER-FIGURE, C_A, AND HALF-DAILY SUM OF K_A, JULY 1, 1942, TO OCTOBER 22, 1943 (COEFFICIENT OF LINEAR CORRELATION 0.952 ±0.002)

ings worked out independently by IRPL for radio propagation-disturbance and by DTM CIW for ionospheric disturbance, but it is felt that a discussion of the actual forecasts issued by IRPL is more pertinent than a comparison of the methods used at the two laboratories. It may be noted that during the period in which the forecasts are here evaluated, the old schedule for issuing forecasts four to ten days in advance was in effect.

In the comparison of A-zone forecasts with magnetic character-figures, it was assumed that for complete substantiation a day for which the forecast was 1, 2, or 3 should have magnetic character-figure $20C_A$ of 15 or greater. Similarly, a forecast of 4 should correspond to magnetic character of 9 to 14, a forecast of 5 to character 3 to 8, and a forecast of 6, 7, or 8 to

character 0 to 2. (Forecast-rating 9 was not used during the period analyzed.) The percentage of days in each three-month period from July, 1943, through December, 1944, for which substantiation of the forecast was complete, is shown in Figure 3(A). When a leeway of one step higher or lower is allowed—for instance, a forecast of 4 for days with character 3 to 8, and





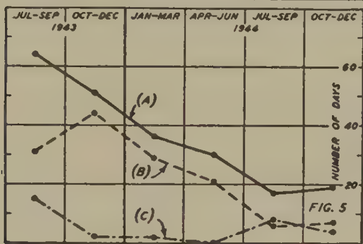


FIG. 3—PERCENTAGE OF DAYS IN EACH 3-MONTH PERIOD ON WHICH SUBSTANTIATION OF A-ZONE FORECASTS WAS (A) COMPLETE, AND (B) SATISFACTORY, JULY, 1943 THROUGH DECEMBER, 1944

FIG. 4—FREQUENCY OF FORECAST-RATINGS AND MAGNETIC DISTURBANCE, SHOWING LINES OF REGRESSION, JULY, 1943 THROUGH DECEMBER, 1944

FIG. 5—(A) TOTAL NUMBER OF MAGNETICALLY DISTURBED DAYS; AND NUMBER OF DISTURBED DAYS WITH FORECAST-RATING (B) 1-4, AND (C) 6-8, IN EACH 3-MONTH INTERVAL, JULY, 1943 THROUGH DECEMBER, 1944

15 or greater as well as 9 to 14—the percentages are as shown in Figure 3(B). In this computation, days of character 0 were counted only if the forecast was 6, 7, or 8. The percentages shown are almost constant except for the low value in October to December 1944. In general, 35 per cent of all days were forecast with high accuracy, and 70 per cent with fair accuracy. Figure 4 is a frequency-diagram for the 18-month period classifying days according to the adopted forecast and disturbance-ranges. The coefficient of linear correlation is $+0.32 \pm 0.03$, and the lines of regression are as shown. The probability that as large a correlation would arise by chance is considerably less than 0.01.

The forecast of disturbed days is perhaps more important than those of quiet days from the point of view of the user. Figure 5 shows the total number of disturbed days ($20C_A \geqslant 9$) in each three-month interval as in curve A and also the number of disturbed days which were given a forecast-rating of 1, 2, 3, or 4 as in curve B, and the number which were given a rating of 6, 7, or 8 as in curve C. The number of magnetic disturbances of the assumed severity decreased markedly during the period under examination. However, very few disturbed days came unannounced—no more than eight in any quarterly period since October, 1943.

These methods of evaluation assume that the numerical designation given in the forecast is an estimate of the amount of expected geomagnetic activity, whether large or small. The forecasts may also be interpreted as the probability that significant magnetic disturbance will occur. Figure 6 shows the percentage of days during July, 1943, through December, 1944, with each forecast-rating which actually had disturbed (*A*), severely disturbed (*B*), quiet (*C*), and very quiet conditions (*D*). For instance, 73 per cent of days given a forecast-rating of 1, 2, or 3 were disturbed and 51 per cent were severely disturbed, while the corresponding percentage for days given a forecast-rating of 6, 7, or 8 were 27 and 13, respectively. Figure 7 gives the percentage of days in each disturbance-range which had forecast-ratings of 1 to 4 (*A*), 1 to 3 (*B*), 5 to 8 (*C*), and 6 to 8 (*D*). From this it is seen that the more disturbed the forecast-rating, the larger the percentage of disturbed and very disturbed days, and the smaller the

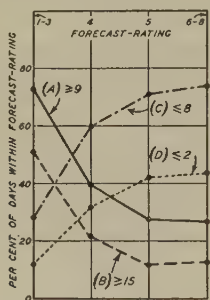


FIG. 6—PERCENTAGE OF DAYS WITH EACH FORECAST-RATING, WHICH WERE (A) DISTURBED, (B) SEVERELY DISTURBED, (C) QUIET, AND (D) VERY QUIET, JULY, 1943 THROUGH DECEMBER, 1944

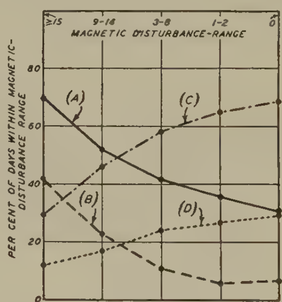


FIG. 7—PERCENTAGE OF DAYS IN EACH MAGNETIC-DISTURBANCE RANGE WITH FORECAST-RATING OF (A) 1-4, (B) 1-3, (C) 5-8, AND (D) 6-8, JULY, 1943 THROUGH DECEMBER, 1944

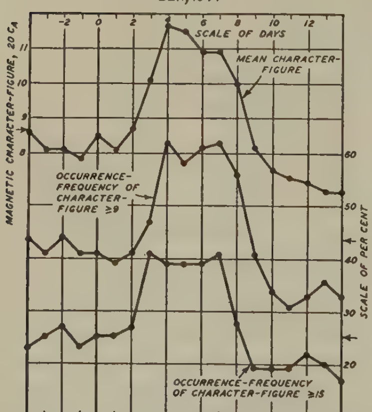


FIG. 8—SUPERPOSED-EPOCH DIAGRAM SHOWING MAGNETIC ACTIVITY WITH REFERENCE TO DAY OF FIRST APPEARANCE OF BRIGHT CORONAL REGIONS ON EAST LIMB, AUGUST, 1942 TO JULY, 1944 (ARROWS AT BORDERS LOCATE MEAN VALUES FOR ENTIRE PERIOD)

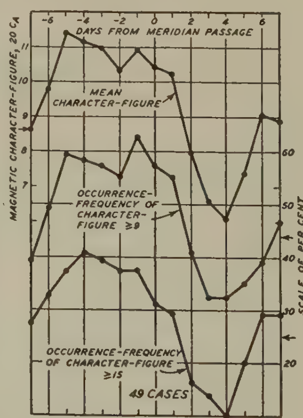


FIG. 9—SUPERPOSED-EPOCH DIAGRAM SHOWING MAGNETIC ACTIVITY WITH REFERENCE TO MERIDIAN PASSAGE OF LARGE PLAGES, AUGUST, 1942 TO JULY, 1944 (ARROWS AT BORDERS LOCATE MEAN VALUES FOR ENTIRE PERIOD)

percentage of quiet and very quiet days. In addition, the larger the amount of magnetic activity, the greater the relative number of disturbed forecast-ratings issued and the smaller the number of quiet forecasts made. This relationship is fairly consistent throughout the whole range of forecast- and disturbance-ratings. Although there is room for improvement, especially as concerns forecast-rating 4, the relationship is definitely in keeping with the idea that the forecasts may properly be interpreted in terms of the probability of occurrence of disturbance.

The decrease in the degree of substantiation of the forecasts in the last quarter of 1944 may be attributed to the failure of the 27-day recurrence-tendency to be operative in detail and to the dearth of solar data because of unfavorable observing conditions. It is also noted that high-latitude solar regions connected with the new sunspot-cycle became increasingly predominant during 1944. Not enough instances of disturbances associated with these regions occurred during the year to allow revision of the statistical solar-geomagnetic correlations derived principally from disturbances associated with low-latitude solar regions.

In general, the success of the forecasts has varied with the type and number of disturbances that occur. In many cases the relative forecast-ratings on successive days reflected the trend of geomagnetic activity, but the magnitude of activity indicated was in error because of a change in the general level of activity since the previous 27-day cycle. For instance, 11 out of 12 days beginning April 26, 1944 (see Fig. 1), were appreciably disturbed, while one cycle later only three of the corresponding days were disturbed. Conversely, four days were disturbed during July 17 to 25, 1943, and all of the corresponding days in the succeeding cycle were disturbed. In many cases observed changes in the activity of solar regions correlate with such changes in the character of the magnetic disturbance-pattern.

The well-marked 27-day recurrence-sequences which prevailed until May, 1944, materially aided the forecasts up to that time. The forecasts were then based principally on recurrence-tendency but with modifications both in timing and severity of disturbance as indicated by the position and activity of the associated solar regions. Since May, 1944, the recurrence-tendency has not been reliable in detail. General periods of disturbance are indicated in the recurrence-diagram, but solar relationships assumed a greater importance in the designation of disturbed days.

Correlation of coronal and magnetic activity

One of the statistical relationships between solar and magnetic activity used in short-term forecasts has been based on observations of the intensity of the solar corona which have been made systematically at the Climax (Colorado) Station of the Harvard College Observatory since the inception of the coordinated solar program. An early account of the correlations

derived appeared in a previous report (see 1 of "References" at end of report), and a more comprehensive report is also available [2].

Regions of the solar corona observed at the east limb of the Sun by spectrographic observations of the coronal green-line (λ 5303) are subsequently carried to the visible solar disk by the solar rotation. Intense emission-regions of the corona are sometimes, but not always, associated with sunspot-groups. The correlation between the intensity of a coronal region and the size or complexity of sunspots, or with the size or intensity of calcium plages, is not high. To a certain extent the coronal observations seem to identify a different set of active solar regions than direct or spectroheliographic observations. Coronal observations of a region are possible one to three days in advance of the time disk-manifestations of the region become visible, and thus are of especial use in forecasts.

Coronal regions may be designated significant if the maximum intensity of the green-line is above a preselected limiting-value. A relationship is then sought between the time of appearance on the limb of significant coronal regions and the occurrence of magnetic activity. One form of analysis is by the superposed-epoch method devised by Chree for studying the 27-day recurrence-tendency of magnetic activity. Daily magnetic character-figures are tabulated so that the character-figures for each day when a bright coronal region was first observed on the east limb are aligned in one column, and the character-figures for n days after the event are likewise in adjacent columns. From this, the average magnetic character and the occurrence-frequency of disturbed days on the nth day after first appearance of a significant coronal region on the east limb are computed. Figure 8 shows such a superposed-epoch diagram for August, 1942, to July, 1944, where $20C_i$ is taken to indicate daily magnetic character, and $20C_i$ of 9 and 15 are the lower limits for two classes of disturbed days. The criterion for a significant coronal region is an intensity of ten units on the arbitrary intensity-scale used at Climax.

Figure 8 shows that an abrupt increase in average magnetic activity occurred three and four days after first appearance of the bright coronal region. The increase in occurrence-frequency of disturbed days was especially marked. A significant decrease in average activity occurred beginning nine or ten days after east-limb passage of the region.

The statistical relationship between time of appearance of bright coronal regions and the incidence of magnetic activity have been used with some success in the short-term forecasts of propagation-conditions. Unfortunately the coronal data, coming at present from a single station, are frequently incomplete, especially during the periods of unfavorable observing weather in winter.

The characteristics of a solar region are observable in the corona in advance of observations of disk and it is usually not possible to assess the

potentialities of a disk-region when it is near the solar limb. For these reasons a coronal-magnetic relationship is more useful in short-term forecasting of disturbance than a relationship between magnetic activity and disk-phenomena even if the corona and some disk-feature identify the same active solar region. There have been many instances when the coronal-magnetic relationship assumed the average form and the calcium plage associated with the coronal region was insignificant by all normal criteria. The high energy required to produce the emission of the coronal lines indicates that the corona is probably a more fundamental phenomenon with which correlations of geomagnetic activity may be made.

We have considered in these analyses magnetic activity that under ordinary circumstances would not have been called significant, because the ionospheric disturbances associated with even this small activity assume importance. The analyses are intended to derive solar-geomagnetic relationships that hold for the present stage of solar and geomagnetic activity, in order to develop the technique of forecasting disturbances. Some discussion of the significance of the correlations appears in another report [2].

Correlation of calcium plages and magnetic activity

The statistical relationship between meridian passage of calcium plages and the occurrence of magnetic activity is somewhat similar though not quite so definitive as the coronal-magnetic relationship for the same period. A superposed-epoch analysis does not show a significant relationship when long-lived plages, visible for ten or more days, which have an area less than 2000 millionths of the solar disk, are used. However, magnetic activity occurred on the average when long-lived plages larger than 2000 millionths were east of the solar meridian, as indicated by Figure 9, a superposed-epoch diagram for August, 1942, through July, 1944. Greater than normal magnetic activity took place on the average from the time the large plages were six days east until they were one day west of the meridian, a total of eight days, compared with six for the coronal-magnetic relationship.

Of the 49 plages included in the above analysis, 37 were in low latitude—less than 19°. Taken alone, these show a similar relationship to magnetic activity [Fig. 10(A)]. The 12 high-latitude plages of area greater than 2000 millionths give a more erratic result. In Figure 10(B), there are maxima at six and three days before meridian passage, and a third at meridian passage of the region.

The data accumulated in two years proved insufficient to show conclusively a systematic variation in the correlation of magnetic activity and plages at different minimum distance from the center of the solar disk. During the period studied only a few cases of high-latitude groups associated with magnetic disturbance were observed. The correlation derived is principally for equatorial plages and the corresponding form of the rela-

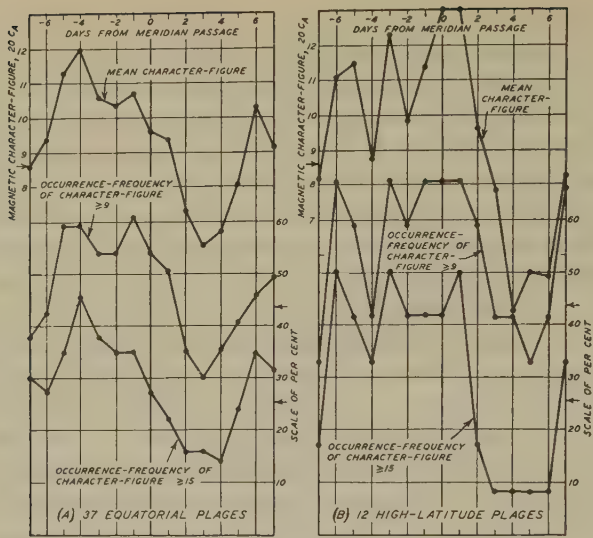


FIG. 10—SUPERPOSED-EPOCH DIAGRAM SHOWING MAGNETIC ACTIVITY WITH REFERENCE TO MERIDIAN PASSAGE OF LARGE PLAGES IN (A) EQUATORIAL AND (B) HIGH LATITUDE, AUGUST, 1942 TO JULY, 1944 (ARROWS AT BORDERS LOCATE MEAN VALUES FOR ENTIRE PERIOD)

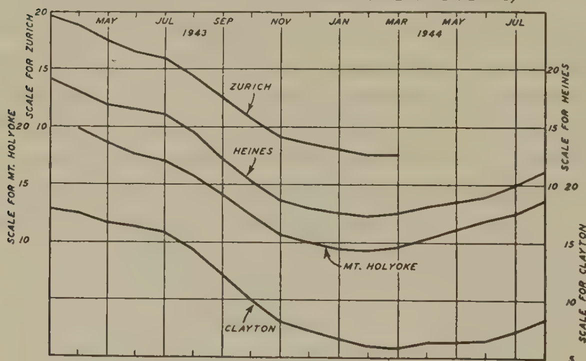


FIG. 11—TWELVE-MONTH RUNNING MEAN OF RELATIVE SUNSPOT-NUMBER, R, FROM FOUR OBSERVERS, MARCH, 1943 TO AUGUST, 1944 (OBSERVATORY CONSTANT FOR 1943 USED FOR ALL OBSERVATIONS)

tionship for high-latitude plages, which are now becoming more common, must await accumulation of data.

This analysis necessarily refers only to plages which are active for many days in succession. Plages which change during disk-passage will not always be included in the data used, although in many cases magnetic disturbances may be attributed to such regions.

Progress of solar-activity cycle

Solar activity reached a low point during the first half of 1944 when sunspots were seen on only one day in February and three in April. Also during the year high-latitude regions of the new sunspot-cycle became pre-

dominant proportionally as the old sunspot-cycle declined. The change from high- to low-latitude characteristics is also apparent from the coronal and spectroheliographic observations since 1942.

The 12-month mean of the relative sunspot-number apparently reached a minimum point in February or March, 1944. Figure 11 shows the course of activity since March, 1943, as derived from Zürich observations (as far as they are available) and from the observations of three American sources (Heines, Mt. Holyoke College, and Clayton). The last two months for which 12-month running means can be computed for Zürich (February and

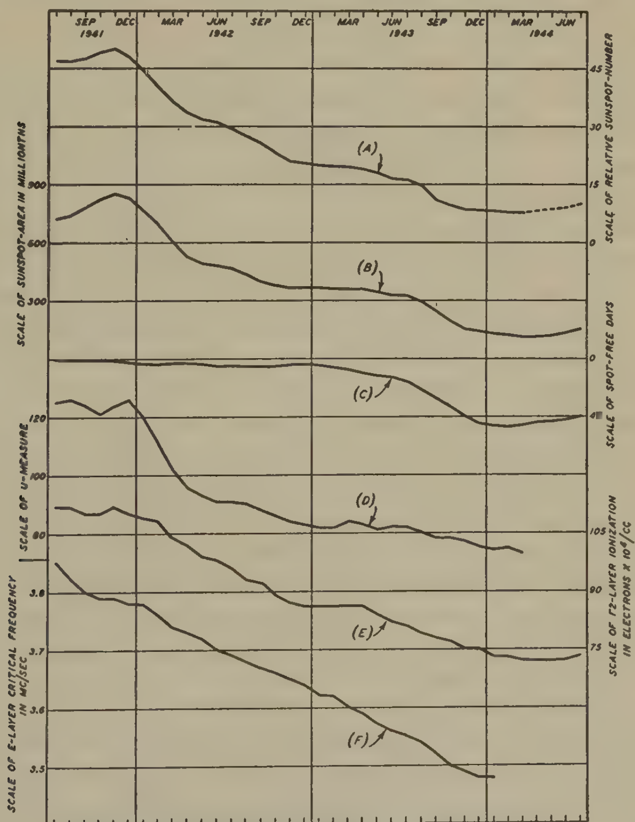


FIG. 12—TWELVE-MONTH RUNNING MEANS, JULY, 1941 TO JULY, 1944: (A) RELATIVE SUNSPOT-NUMBER; (B) MEAN DAILY SUNSPOT-AREA; (C) PERCENTAGE OF SPOT-FREE DAYS; (D) u-MEASURE OF MAGNETIC ACTIVITY, HUANCAYO; (E) F^2-LAYER ION-DENSITY, 09^h, 75° WEST MERIDIAN TIME, HUANCAYO; AND (F) E-LAYER CRITICAL FREQUENCY, 12^h, 75° WEST MERIDIAN TIME, HUANCAYO

March, 1944) give identical mean sunspot-numbers, ending a downward trend that had lasted for several years. The observations from each of the American observers show a minimum point in February or March, 1944, and a definite increase in sunspot-activity in the mean for succeeding

months. The average observatory constant for 1943 has been used to reduce the American observations to the scale at Zürich.

Various solar and geomagnetic indicators of the 11-year cycle are shown in Figure 12. Twelve-month running means of Zürich-Heines relative sunspot-numbers, and mean daily sunspot-area and per cent of spot-free days taken from the United States Naval Observatory summaries of their own and Mount Wilson observations, all have a minimum between February and April, 1944. The u-measure of magnetic activity for data from Huancayo has decreased fairly regularly with the decline of solar activity. As far as the 12-month mean for March, 1944, including reductions of observations through September, there is no well-defined minimum. The minimum in the 11-year magnetic activity-cycle has usually in the past succeeded minimum solar activity, and the present instance seems not to be an exception. The 12-month running mean of $F2$-layer ion-density, computed from the formula $N = 1.24 \times 10^4 f^2$, where f is the penetration-frequency expressed in Mc/sec, has shown, in the case of Huancayo (at 09^h, 75° WMT), a slight increase for the period centered at July, 1944, over that for June. The E-region critical frequency at noon at Huancayo has shown a steady decrease in the last three years, though no definite minimum point has been reached up to January, 1944. Thus, while it seems that solar activity went through a minimum early in 1944, the epoch of minimum magnetic activity and ion-density in the ionosphere is not yet definitely established.

Previous to 1944 a large percentage of the solar regions observed as sunspots or calcium plages were in low heliographic latitudes, belonging to the old sunspot-cycle. Since then the high-latitude groups have become proportionately more common and the sunspot-polarities are opposite to those of low-latitude spots. The percentage of groups in latitudes greater than 15° in each half-year is given in Figure 13. It is obvious that if latitude of solar groups has any effect on the relationship of solar activity to geomagnetic disturbance, there should be a change in the nature of the correlation found in 1943 and 1945. While no quantitative statement of such a change can yet be made, it is noted that well-marked 27-day recurrence-sequences ceased early in 1944, and with them the tendency for extended periods of generally disturbed conditions to occur (Fig. 1). Towards the end of 1944 the magnetic and ionospheric disturbances were of relatively short duration and were usually followed by exceptionally quiet conditions. The disturbances that did occur were in most cases associated with high-latitude regions.

The effect of the increasing prevalence of high-latitude regions on the distribution of the coronal green-line is demonstrated in Figure 14(A) which shows total intensity of the green-line in per cent of maximum for every half-year as observed at Climax at 5°-intervals of heliographic latitude. The high-latitude regions show as a secondary maximum in the second

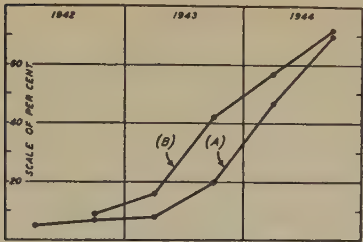


FIG. 13—PERCENTAGE OF (A) SUNSPOTS, AND (B) CALCIUM PLAGES, OBSERVED IN HELIOGRAPHIC LATITUDES GREATER THAN 15° FOR EACH HALF-YEAR, 1942-44

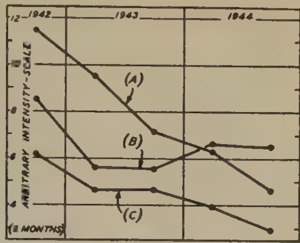


FIG. 15—MEAN INTENSITY OF GREEN CORONAL LINE IN (A) LOW-LATITUDE ZONE [±15°], (B) HIGH-LATITUDE ZONE [±20° TO ±45°], AND (C) POLAR ZONE [±50° TO ±90°], FOR EACH HALF-YEAR, AUGUST, 1942 THROUGH DECEMBER, 1944

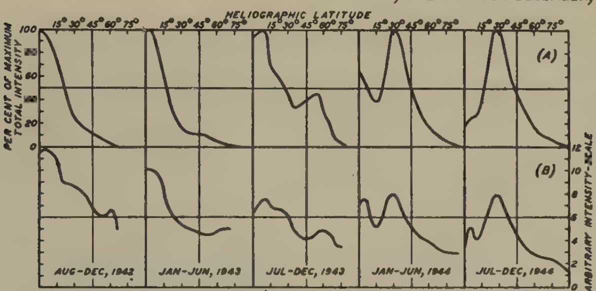


FIG. 14—LATITUDE-DISTRIBUTION OF (A) TOTAL INTENSITY OF GREEN CORONAL LINE IN PER CENT OF MAXIMUM, AND (B) MEAN INTENSITY FOR EACH HALF-YEAR, AUGUST, 1942 THROUGH DECEMBER, 1944

half of 1943, and become very marked in 1944. The latitude-distribution of the mean intensity of the coronal green-line [Fig. 14(*B*)] shows that the high-latitude regions are becoming increasingly bright as well as more common. Figure 15 divides the corona at the limb into three zones roughly corresponding to low, high, and polar latitudes. The mean intensity of the corona in low latitudes has steadily decreased, while an increase is evident from 1943 to 1944 in high latitudes. The intensity of the corona near the pole decreased steadily through 1944, but polar corona was observed more often.

Although the coronal data on which the diagrams are based are affected by variable observing conditions, which influence the minimum intensity observed, and also the data do not represent observations on every day during the period, the trend shown is as would be expected, except perhaps for the latter part of 1942. This fact would appear to strengthen the statistical reliability of the coronal data, in particular the arbitrary scale of intensity.

The amount of solar activity at the minimum of 1944 has been, by all indicators, greater than at the time of the previous minima in 1923 and 1933, as is shown for relative sunspot-numbers, mean daily sunspot-area, and percentage of spot-free days in Figure 16. The 12-month running mean of Zürich sunspot-numbers decreased to 7.7 in February and March, 1944. The

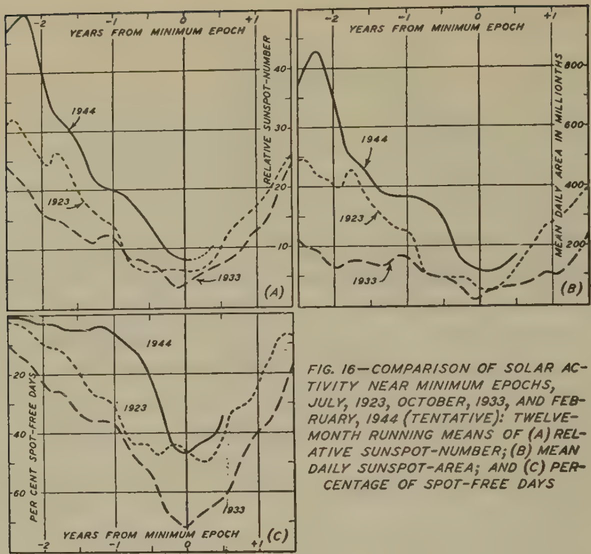


FIG. 16—COMPARISON OF SOLAR ACTIVITY NEAR MINIMUM EPOCHS, JULY, 1923, OCTOBER, 1933, AND FEBRUARY, 1944 (TENTATIVE): TWELVE-MONTH RUNNING MEANS OF (A) RELATIVE SUNSPOT-NUMBER; (B) MEAN DAILY SUNSPOT-AREA; AND (C) PERCENTAGE OF SPOT-FREE DAYS

observations of various American observers indicate an increase in the mean value since that time such that a lower mean will not be possible later in 1944. Compared with this, the mean at minimum was three in 1933 and six in 1923. The mean daily area of sunspots in the 12 months centered at both March and April, 1944, was 116 millionths of the Sun's visible hemisphere as compared with 17 millionths for September, 1933, according to the United States Naval Observatory summaries. The Greenwich photoheliographic results give 50 as the comparable figure for August, 1923. At the minimum of 1933, 72 per cent of days in a 12-month interval were free of spots, 50 per cent were free of spots in 1923, while 47 per cent is the largest value of spot-free days at the minimum point in 1944.

Just as the amount of solar activity at the minimum in 1944 has been unusually large, magnetic activity may be expected to be greater at its minimum point. The value of u for March, 1944, 0.73, is considerably higher than the minimum values in 1923 and 1934, 0.65 and 0.66, respectively. Any estimate of the future course of the solar cycle necessarily contains a good deal of uncertainty. However, it appears from Figure 16 that the magnitude of the present minimum solar activity is similar to that at the minimum in 1923 rather than that in 1933. The minimum came somewhat more abruptly than in either earlier case, and so far the curves lack the broad plateau, or period of continual low activity, which is characteristic of 1923 and 1933. It is noted that if the curve for 1944 is projected parallel to that for 1923 for any of the three indicators of solar activity, the level of activity a year before minimum, namely, February, 1943, is regained in 14 or 15 months, or about April or May, 1945.

Visually recording magnetographs

Three visual recorders of a type mentioned in a previous report [1] have been constructed for use with magnetic variometers to give an instantly visible record of variation of the Earth's magnetic field. The recorder and the universal variometer designed by Vestine are described in detail in a separate report [3]. Figures 17 and 18 show the instrument completely assembled and with the viewing-hood removed. The recorder is designed so that almost two days' record is visible at one time. Eastman "Print-out" recording paper is used, and the trace is viewed through a red-filter hood.

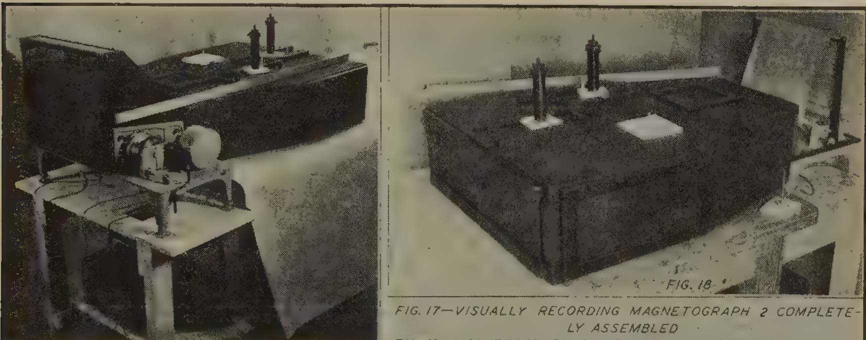


FIG. 17

FIG. 18

FIG. 17—VISUALLY RECORDING MAGNETOGRAPH 2 COMPLETELY ASSEMBLED

FIG. 18—MAGNETOGRAPH 2, VIEWING-HOOD REMOVED TO SHOW RECORD

Two instruments have been installed at high-latitude ionospheric stations operated by DTM CIW. The third has been set up at the Sterling (Virginia) Station of IRPL. The visible record of magnetic activity aids considerably in the recognition of geomagnetic disturbance and is used in connection with the IRPL daily storm-warning service.

Conclusion

It is evident that short-term forecasting of ionospheric conditions has been based on diverse criteria, both solar and geomagnetic, all of them contributing something to the final product. The organized reporting of data on a fast schedule is indispensable to the undertaking. In particular, solar data are required for forecasting beyond the reliability of the 27-day recurrence-tendency, and for maximum effectiveness the data must have few discontinuities with similar observing programs. It is, however, quite evident that solar-geomagnetic relationships are still too general to be sole factors in detailed forecasts. The manifestation, if any, of the solar cause of geomagnetic disturbance has not yet been found. Awaiting the discovery of a useful one-to-one solar-geomagnetic relationship, we can increase the utility of solar data in forecasting by placing the known relationships, if

possible, in more definitive form, thus removing some of the subjective judgment that now enters into the preparation of forecasts.

References

[1] A. H. Shapley and H. W. Wells, Correlation of solar and geomagnetic observations with conditions of the ionosphere, unpublished report, September, 1943.

[2] A. H. Shapley and W. O. Roberts, The correlation of magnetic disturbances with intense emission regions of the solar corona, Astrophys. J., **103** (1946), in press.

[3] K. L. Sherman and E. H. Vestine, Description of DTM visually recording magnetograph and directions for operation, unpublished report, May, 1944.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., March 30, 1945

FINAL RELATIVE SUNSPOT-NUMBERS FOR 1945

By M. Waldmeier

Table 1 contains the final sunspot-numbers for 1945 for the whole disk of the Sun, based on observations made at the Zürich Observatory, supplemented by series furnished by other cooperating observatories. Table 2 gives the number of spot-groups on each day for the year 1945. The yearly mean of the group-numbers is 3.0. The yearly mean of the relative-numbers is 33.2, against 9.6 in 1944. The number of spotless days has diminished

Table 1—*Final relative sunspot-numbers for the whole disk of the Sun for 1945*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	6	7	13	50	62	20	14	23	37	87	56	48
2	0	8	23	57	55	10	0	26	35	82	45	38
3	0	18	18	52	52	22	7	24	26	82	37	34
4	0	23	22	50	39	8	8	23	31	67	35	36
5	14	20	26	38	34	22	19	19	25	70	29	32
6	26	10	14	32	43	22	34	17	46	81	44	30
7	29	8	14	28	35	23	18	36	39	93	38	21
8	23	9	15	8	20	8	32	24	47	71	31	27
9	17	14	22	8	34	19	29	30	35	71	37	17
10	17	0	21	7	16	21	51	35	39	64	29	19
11	30	0	22	0	20	35	57	38	38	31	31	20
12	23	0	19	0	8	42	80	53	23	29	33	30
13	20	16	20	7	0	50	100	63	9	41	49	40
14	21	10	11	10	9	53	98	70	16	47	65	42
15	20	14	10	10	22	53	105	71	0	50	66	38
16	18	14	0	20	43	68	99	51	7	50	48	34
17	14	15	8	21	46	70	88	34	19	55	42	46
18	23	13	8	23	50	67	76	34	8	71	52	42
19	17	29	15	32	47	59	87	33	13	98	57	34
20	16	18	15	32	26	64	53	20	20	96	46	23
21	31	7	16	31	27	62	41	0	17	78	39	19
22	41	7	13	31	19	56	35	0	41	57	45	18
23	23	11	14	38	26	48	27	8	66	89	57	20
24	23	12	14	29	32	39	28	16	77	76	54	18
25	16	19	17	52	36	28	31	8	57	59	57	18
26	10	22	21	46	24	25	33	0	53	68	63	18
27	29	16	35	56	31	26	8	0	35	79	53	18
28	25	16	36	55	23	23	19	9	55	86	58	19
29	17		60	71	22	19	18	10	49	68	35	14
30	15		63	67	19	23	17	8	84	65	48	15
31	11		63		28		9	20		71		22
Mean	18.5	12.7	21.5	32.0	30.6	36.2	42.6	25.9	34.9	68.8	46.0	27.4

from 159 in 1944 to 16 in 1945. Figure 1 gives a graphical representation of the daily relative sunspot-numbers of 1945, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive

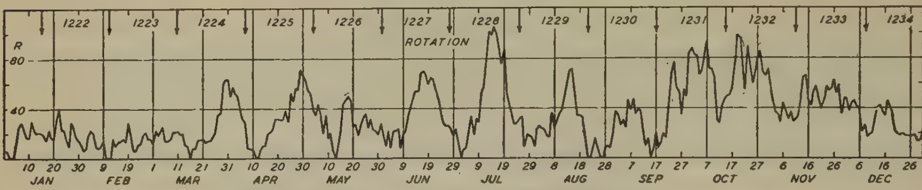


FIG 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1945

TABLE 2—*Daily numbers of sunspot-groups for 1945*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	1	1	1	3	5	2	2	3	4	6	6	3
2	0	1	2	4	5	2	0	3	4	5	5	3
3	0	2	2	4	4	2	1	3	3	5	4	2
4	0	2	2	4	4	1	1	3	4	4	4	2
5	2	2	3	3	3	3	2	2	3	4	3	2
6	3	2	1	3	4	3	4	2	5	6	4	2
7	4	1	1	3	3	3	2	4	4	6	4	2
8	3	1	1	1	2	1	4	3	5	6	4	3
9	2	2	2	1	4	2	3	3	5	6	5	2
10	2	0	2	1	2	1	4	3	4	6	4	2
11	3	0	2	0	3	3	5	3	5	3	3	2
12	2	0	2	0	1	4	6	5	3	3	3	3
13	2	2	3	1	0	6	6	5	1	4	5	4
14	2	1	2	1	1	5	6	6	2	4	7	5
15	2	1	1	1	2	5	8	6	0	4	7	5
16	3	1	0	2	4	6	8	4	1	5	5	4
17	2	1	1	2	4	5	8	2	2	3	4	5
18	3	1	1	2	5	6	7	3	1	5	5	5
19	2	3	2	3	5	5	8	4	1	8	5	4
20	2	2	2	2	3	5	5	3	2	8	4	2
21	3	1	2	2	3	5	3	0	2	6	4	2
22	4	1	1	2	2	5	3	0	4	4	5	2
23	3	1	1	3	3	4	2	1	4	6	6	2
24	3	1	1	2	4	3	2	2	5	6	5	2
25	2	2	1	4	4	2	3	1	3	5	5	2
26	1	2	1	3	3	2	4	0	3	6	6	2
27	2	1	2	4	4	2	1	0	2	7	5	2
28	2	1	3	4	3	2	2	1	5	7	6	2
29	1		3	5	2	2	2	1	4	6	3	1
30	1		4	5	2	3	2	1	5	5	4	1
31	1		4		3		1	2		6		2
Mean	2.0	1.3	1.8	2.5	3.1	3.3	3.7	2.5	3.2	5.3	4.7	2.6

solar rotations are indicated by vertical arrows in the upper edge of the Figure.

In this report I have introduced two slight modifications[1]: (*a*) The indications for birth, death, and time of central-meridian passage of the sunspot-groups are omitted. In 1926, when Prof. Brunner had introduced these indications, some astronomers believed that it was the birth, some others that it was the death, and still others that it was the central-meridian passage that is responsible for terrestrial effects! Now we know that these assumptions had failed, except for the very large and active groups, which form a very small fraction of all groups. Even with the largest spots, of which not more than half a dozen occur in each cycle, the probability to have a terrestrial effect in the days of central-meridian passage is only 0.6. Full information of birth, development from day to day, position on the Sun's disk, etc., of all spot-groups will be given as usual in the heliographic maps of the Sun, published in the *Publikationen* of our observatory. (*b*) I have introduced the new Table 2, giving the daily numbers of spot-groups, as especially American astronomers refer often not only to the relative-numbers but also to the group-numbers.

Eidgen. Sternwarte,
Zürich, Switzerland, March 7, 1946

[1]See Terr. Mag., 50, 231-232 (1945) for last report.

A PREDICTION OF THE NEXT MAXIMUM OF SOLAR ACTIVITY

By M. Waldmeier

In a recent issue of this Journal A. H. Shapley[1] has given a prognostic of the Sun's activity up to the year 1950, according to which the next maximum will occur in 1949.6 and be characterized by the highest smoothed monthly relative number $R_M = 80$. But as this prognostic is based on the assumption of alternating maxima and moreover makes use, not of the well-defined minimum, but of the much less accurately observable starting point of a new cycle, it should hardly be able to represent the approaching period of solar activity in a satisfactory manner.

We therefore give here the development of solar activity during the coming maximum as computed by a method proposed by the present author[2], and which had already led to very satisfactory results for the maximum of 1937. The greatest smoothed relative number will be, according to this computation, $R_M = 139$, and the maximum should be expected to take place as early as 1947.6. The following formulas

$$
\begin{aligned}
R_{-2} &= -(0.225 + 0.092)R_M + (51.0 + 10.5)\\
R_{-1} &= -(0.072 + 0.098)R_M + (26.0 + 9.4)\\
R_1 &= +(0.823 + 0.043)R_M - (1.4 + 4.6)\\
R_2 &= +(0.686 + 0.057)R_M - (4.8 + 7.9)\\
R_3 &= +(0.553 + 0.061)R_M - (10.9 + 8.5)\\
R_4 &= +(0.380 + 0.070)R_M - (5.2 + 9.8)\\
R_5 &= +(0.301 + 0.071)R_M - (7.4 + 9.9)
\end{aligned}
$$

give then the smoothed monthly relative numbers for the epochs two years before to five years after the maximum. The values for the approaching maximum are accordingly

$R_{-1} = 89$	$R_1 = 113$	$R_3 = 66$	$R_5 = 30$
$R_0 = 139$	$R_2 = 91$	$R_4 = 48$	$R_6 = 17$

We should therefore expect a very rapid increase of the solar activity leading up to an unusually intense maximum.

Swiss Federal Observatory,
Zürich, Switzerland, April 10, 1946

[1]A. H. Shapley, Terr. Mag., **49**, 43 45 (1944).

[2]M. Waldmeier, Astr. Mitt., Eidgen. Sternwarte, Zürich, No. 133 (1935).

PROVISIONAL REPORT OF THE SECRETARY, INTERNATIONAL ASSOCIATION OF TERRESTRIAL MAGNETISM AND ELECTRICITY FOR THE PERIOD 1939-45

By A. H. R. Goldie

War history—The Secretary had been due to sail from England for U. S. A. on August 26, 1939. A few days before that date the intended sailing of various British delegates, including the Secretary, was cancelled owing to the imminence of war. All papers for the Washington Assembly had been made ready and had previously been sent on to Washington, and Dr. Joyce acted as Secretary during the meetings.

Executive Committee—Dr. G. van Dijk died during the war. No information is available yet about Professor Tanakadate. The other members, so far as is known, are well.

Activities and publications—Since many of the papers and reports intended to appear in the *Transactions* of the Washington Meeting had been set up in proof, it was decided that the best course was if possible to complete the printing of volume Bulletin No. 11—before greater difficulties supervened. With the assistance of notes supplied by Dr. Joyce, the volume was completed and the printing was finished (in Edinburgh) by October, 1940.

Copies were distributed within the British Isles, to the Argentine, Brazil, Canada, Egypt, India, New Zealand, Siam, South Africa, U. S. A., and Uruguay, the number so disposed of being about 457. The losses in transit through enemy action are not fully known but out of 320 copies sent to U. S. A., 300 arrived safely. The remaining stock of 443 copies was divided into two portions and stored for safety, one at Edinburgh and the other at Eskdalemuir. These stocks are both now available for issue.

The President was able to arrange for the inception of the three-hour-range index (Resolution 2) and for the collection of the appropriate data to the Carnegie Institution of Washington. During the war, collection and coordination of data relating to magnetic activity have so far as possible been maintained by the Carnegie Institution of Washington and summaries have been published in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*. It is to be hoped that this may continue until replaced—if it is ever replaced—by a new international arrangement. Dr. van Dijk, who formerly handled the magnetic-activity data, has died and it is not known whether anyone at the De Bilt Observatory could in any case resume the work.

Finances—The balance of the funds continues to be held in pounds sterling with the National Bank of Scotland, Edinburgh, a small rate of

interest having been earned on certain funds on deposit account. After the settlement of accounts concerned with the printing and distribution of Bulletin No. 11 there were few transactions to record. The funds in hand, December 31, 1945, amount to over £3128 as indicated in the following copy of accounts (not yet audited).

Regarding particular items of expenditure and income during the four years ending December 31, 1942, the complete accounts for which period have been examined and certified correctly stated and sufficiently vouchered, by the auditor, the following comments are made:

(1) Nine hundred copies of the *Transactions* of the Washington Meeting were printed at a cost of £538 8s 5d. The intention had been to print 1600 copies, but because of the rationing of paper the number was limited to 900 copies.

(2) The last grants made to Dr. G. van Dijk for the preparation of *Caractère magnétique numérique des jours* and *Caractère magnétique de chaque jour* were £100 and £30, respectively, on August 12, 1939.

(3) The last grant made to Professor Carl Störmer for distribution of auroral atlases, etc., was £10 5s 0d on August 4, 1939.

(4) The last payment received from the General Secretary of the Union was £229 17s 4d in March, 1940; in March, 1941, £60 in respect to sale of *Transactions* was received from Dr. Fleming.

(5) Information is not yet available regarding the various investigations formerly in the hands of the late Dr. la Cour.

(6) Of the $250 advanced to Dr. Fleming in February, 1938, on account of preparation of a list of observatories (Resolution I of the Edinburgh Meeting) a report from Dr. Fleming dated November 6, 1945, contains a statement of expenditure, leaving a balance of only $2.47.

Statement of account of income and expenditure for the three years ending December 31, 1945

Income

	£	s	d
Balance of funds, December 31, 1942, as per audited statement for four years ending December 31, 1942	3034	12	9½
Sale of *Transactions*	1	5	—
Savings account interest	20	5	10
Deposit receipt interest..........................	77	15	5
Total income..........................	3133	19	½

Statement of account of income and expenditure for the three years ending December 31, 1945—Concluded

Expenditure

	£	s	d	£	s	d
Walker and Henderson for audit of accounts				5	5	—
Balance of funds, December 31, 1945..............						
Deposit receipts with National Bank of Scotland, Ltd. ...	2545	6	—			
Savings account	464	13	11			
Current account	116	14	5			
Cash in hand.............	1	19	8½	3128	14	½
Total expenditure and balance..............				3133	19	½

Addresses—President: Dr. J. A. Fleming,
5241 Broad Branch Road, N. W.,
Washington 15, D. C., U. S. A.

General Secretary: Dr. A. H. R. Goldie,
Meteorological Office, Air Ministry,
Headstone Drive, Harrow, Middlesex, England

Air Ministry,
London, England, April 1946

PROVISIONAL SUNSPOT-NUMBERS FOR JANUARY TO MARCH, 1946

(Dependent alone on observation at Zürich Observatory)

Day	January	February	March
1	25	94	96
2	35	103	83
3	34	104	71
4	24	109	92
5	18	110	98
6	12	114	88
7	10	102	65
8	15	91	71
9	19	77	65
10	38	121	78
11	35	115	67
12	21	103	71
13	73	96	57
14	103	79	50
15	109	64	52
16	93	53	49
17	83	58	59
18	59	54	87
19	56	60	106
20	51	45	96
21	58	65	101
22	44	70	97
23	48	67	109
24	59	87	64
25	..	70	55
26	29	90	57
27	45	86	49
28	43	90	60
29	50		60
30	56		87
31	83		94
Means......	47.6	84.9	75.3
No. days....	30	28	31

Mean for quarter January to March, 1946: 69.0 (89 days)

Swiss Federal Observatory,
Zürich, Switzerland

M. Waldmeier

ANNUAL VARIATION OF THE VALUES AT NOON OF THE CRITICAL FREQUENCIES OF THE IONIZED LAYERS AT TROMSÖ DURING 1940, 1941, 1942, 1943, AND 1944

In previous notes the monthly mean values of the critical frequencies of the ionized layers have been given beginning with 1935[1]. In the following the mean monthly values of the critical frequencies determined at local noon will be given. As the station Tromsö is situated near the auroral zone, the conditions of the ionosphere are strongly influenced by the frequent geomagnetic storms, and the echoes are often lacking during disturbed periods due to increased absorption, or more or less irregular echoes appear, which sometimes make a precise critical-frequency determination difficult.

Because of the war it has not been possible to take the observations so regularly as previously, and for some months the number of daily observations are not sufficient to give reliable monthly means. In 1940 the observations had to be stopped on April 10, as the antennas had to be removed due to bombing in the vicinity. The observations could not be resumed until July, 1940. In December, 1944, the antennas had again to be removed.

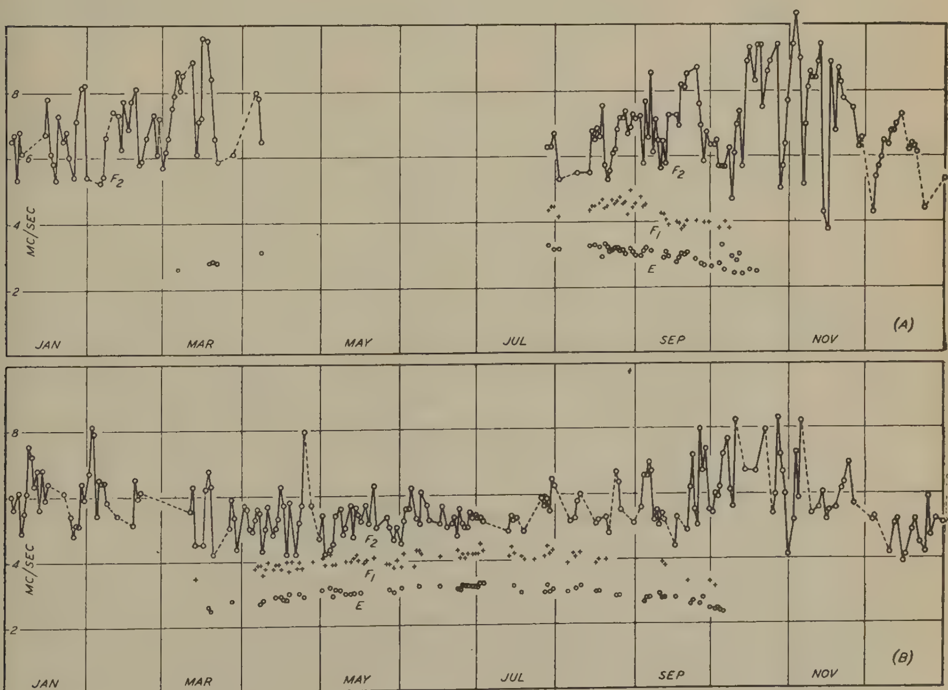


FIG. 1 (A AND B)—VARIATION OF CRITICAL FREQUENCIES, TROMSÖ; (A) 1940, (B) 1941

[1]Terr. Mag., **42**, 55-72 (1937); **43**, 41-43 (1938); **44**, 15-16 (1939); and **45**, 167-168 (1940).

Table 1—*Monthly mean values of critical frequencies in Mc/sec, ordinary component only, determined at local noon, Tromsö (latitude 69°.66 north, longitude 18°.95 east)*

Month	*F*2 for Year					*F*1 for Year					*E* for Year				
	1940	1941	1942	1943	1944	1940	1941	1942	1943	1944	1940	1941	1942	1943	1944
Jan.	6.52	5.98	5.48	4.36	4.40	....	....	....	....	....	....	....	....	....	....
Feb.	6.65	6.32	6.56	5.06	4.88	....	....	....	....	....	....	....	....	....	....
Mar.	7.51	5.81	6.45	5.18	4.70	....	....	(4.00)	(3.80)	3.58	2.75	2.78	2 90	(2.43)	2.50
Apr.	7.41	5.38	5.91	5.10	4.70	....	3.86	4.20	4.06	(3.80)	(3.10)	2.87	3.00	2.72	(2.72)
May	....	5.16	5.75	5.33	4.76	....	4.00	4.36	4.25	3.92	....	3.05	3.14	3.17	2.96
June	....	5.27	4.91	4.93	4.71	....	4.14	4.15	4.21	4.08	....	3.17	3.05	3.11	3.16
July	....	5.53	(4.92)	(4.70)	4.66	....	4.22	(4.10)	(4.10)	(4.10)	....	3.14	(3.10)	(3.08)	3.09
Aug.	(6.07)	5.61	5.30	(4.90)	4.71	(4.40)	4.04	3.90	(4.10)	3.90	(3.27)	3.01	2.80	(2.90)	2.84
Sep.	7.06	6.12	5.02	....	5.22	4.15	3.58	3.83	....	(3.90)	3.05	2.73	2.60	....	2.59
Oct.	7.19	6.45	5.20	4.93	5.66	3.86	(3.15)	....	....	....	2.74	2.41	2.44	....	....
Nov.	7.67	6.10	5.17	4.82	5.37	....	....	....	....	....	....	....	....	....	....
Dec.	6.06	4.85	4.38	4.20	....	....	....	....	....	....	....	....	....	....	....
Mean	(6.90)	5.72	5.42	4.86	4.89	....	4.10[a]	4.13[a]	4.17[a]	4.00[a]	....	3.09[a]	3.02[a]	3.07[a]	3.01[a]

[a]Values for May, June, July, and August only used in these means.

Figure 1 shows the variation of the critical frequencies for the ordinary component, determined at local noon, for the five years. The critical frequencies of the $F1$-layer are only developed during the summer months.

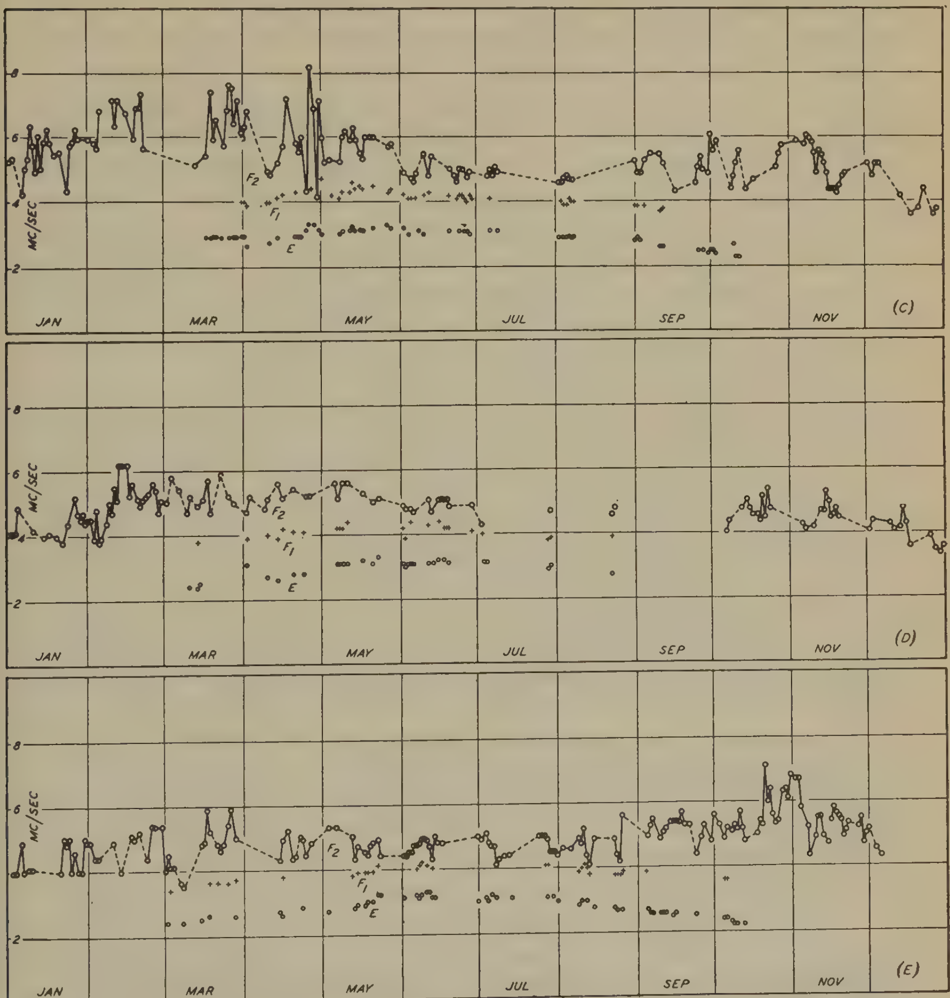


FIG. 1 (C, D, AND E)—VARIATION OF CRITICAL FREQUENCIES, TROMSÖ; (C) 1942, (D) 1943, (E) 1944

In Table 1 the monthly mean values are given for the five years; compared with the preceding years, they show a continuous decrease for all three layers. The decrease is especially pronounced in the values for the critical frequencies of the $F2$-layer.

Leiv Harang

Auroral Observatory,
Tromsö, Norway, September 26, 1945

GEOPHYSICAL OBSERVATORY SODANKYLÄ

The scientific work of the Geophysical Observatory at Sodankylä, which had begun on January 1, 1914, continued without interruption until the final stages of the second world war, despite the fact that military operations sometimes came uncomfortably close to the Observatory, particularly during the winter war 1939-40. In September, 1944, however, it became necessary to leave the Observatory when the entire population of Finnish Lapland was evacuated, and one month later the German military forces razed the Observatory to the ground prior to their retreat from northern Finland. Nothing but ruins was left of a single one of the ten buildings composing the Observatory and the greater part of the recording instruments and the whole library were destroyed. Fortunately, the photographic records, the unpublished and half-finished manuscripts, the greater portion of the absolute instruments, and one magnetic recording set were brought to safety before the German occupation.

The demolition of Sodankylä Observatory was a heavy blow for geophysical science of Finland and also for international work. Aware of this, the Finnish Academy of Science immediately took steps to get the Observatory rebuilt, although at first on a small scale. Unexpected difficulties were encountered, however, during the period of building, as distant Lapland had been laid almost entirely waste during the war. Thus the magnetic variation-house and absolute-house were still incomplete at the end of 1945. Temporary installation of la Cour magnetograph, which had escaped damage, was made in December, 1945. About the same time a small, modest residence, which will serve as the temporary home of the observer, was completed.

It is a pleasure to announce that the geomagnetic recording of Sodankylä Observatory was resumed on January 1, 1946, after an interruption of 15 months.

J. Keränen

Meteorological Office,
Helsinki, February 18, 1946

CIRCULAR LETTER TO ALL ADHERING COUNTRIES INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

(President: Professor B. Helland-Hansen; Acting General Secretary: Dr. J. M. Stagg)

(1) I have the honour to inform you that, following the recommendations of the emergency meeting of the Executive Committee of the International Union of Geodesy and Geophysics held at Oxford in December, 1945, arrangements have now been made to hold an Extraordinary General

Assembly of the Union at Cambridge, England, from July 29 to August 2 or 3, 1946.

(2) Because of exigencies of accommodation and food, as already foreseen at the time of the Oxford Meeting, it is intended that attendance at this Extraordinary General Assembly should be limited to one or at most two delegates from each country, and that the business of the Assembly should be concerned solely with administrative matters. (The recommendation of the Oxford meeting of the Executive Committee was that the first post-war Ordinary General Assembly should be held in Norway in 1947.)

(3) Provisional agenda for the Extraordinary Assembly to be held in Cambridge this summer accompany this circular letter; there is also enclosed a copy of the Proceedings and Resolutions of the Oxford meeting of the Executive Committee [see Terr. Mag., **51**, 103-118, 1946, for preliminary version]. A statement of the accounts of the Union up to the end of 1945 is being prepared for submission to the Cambridge Assembly, and a copy will be distributed to all countries in the very near future.

(4) You will see from the Agenda that one of the items for discussion at Cambridge will be the new draft Statutes (or Convention) and By-Laws (or Rules of Procedure) prepared by Brigadier Winterbotham on request of the Executive Committee at Oxford. A copy of the proposed new Statutes and By-Laws is included as Appendix I to the "Proceedings and Resolutions" of the Oxford Meeting which accompany this letter [see Terr. Mag., **51**, 113-118, 1946]. Appendix II of the same document contains a note on the "Basis of Subscription" on which it is hoped the Extraordinary General Assembly to be held at Cambridge will also make a decision. A separate copy of the new draft Statutes and By-Laws in French will shortly be sent to all countries.

(5) The distribution of the Report on the Seventh General Assembly held at Washington in September, 1939, was much affected by the difficulties and uncertainties of international communications during the war. It is feared that copies sent to many countries never reached them. When replying to this letter, would you please say whether your copies have safely reached you, and if not, how many copies of the Report you require.

(6) As it is now a matter of some urgency to inform the appropriate authorities what the total number of delegates to the Cambridge Assembly is likely to be, it would be appreciated if you could inform me at your early convenience whether you will be able to send a delegate (or delegates) and who they will be. In this connection, it is probably appropriate to mention that many of the administrative matters to be decided at the Extraordinary General Assembly are such as require a two-thirds majority of all adhering countries.

(7) Brigadier Winterbotham relinquished the duties of General Secretary of the Union a few days ago and, following the nomination by the

Executive Committee at its Oxford Meeting, I have taken over his duties (in an acting capacity until accepted by the next General Assembly). It would therefore be appreciated if replies to this circular letter are sent to me at the address given below.

J. M. Stagg, *Acting General Secretary*

Kew Observatory,
Richmond, Surrey, England,
April 14, 1946

PRELIMINARY AGENDA FOR EXTRAORDINARY GENERAL ASSEMBLY, CAMBRIDGE, ENGLAND, JULY 29 TO AUGUST 3, 1946, INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

(1) Opening address by the President of the Union, Professor B. Helland-Hansen

(2) Report on Meeting of Executive Committee in Oxford, December, 1945

(3) Time and place of the next (8th) Ordinary General Assembly

(4) Re-opening of subscriptions to the Union
- (*a*) Basis of subscription: by population or by voluntary choice of category
- (*b*) Size of unit of subscription
- (*c*) Currency in which subscription to be paid

(5) Diplomatic or academic (private) agreement

(6) Revised Statutes and By-Laws

(7) Policy regarding relations between the Union (through the International Council of Scientific Unions) and UNESCO

(8) Financial responsibility for maintenance of services of a permanent nature

(9) Means to increase the number of countries represented in the Union's activities
- (*a*) Countries which have participated but no longer do so (for example, India)
- (*b*) Countries which have never been represented in the Union (for example, Turkey, China, Persia)
- (*c*) Ex-enemy countries (for example, Germany, Austria, Bulgaria, Hungary)

(10) Formation of Committee on the Social Value of the Earth Sciences

(11) Financial statement for the Union to December, 1945

(12) Resolutions of the Washington General Assembly

(13) Association matters including effect on the Union of decision of International Meteorological Organisation to dispense with some

of its technical Commissions (for example Terrestrial Magnetism and Atmospheric Electricity)

(14) Any other business

J. M. Stagg, *Acting General Secretary*

Kew Observatory,
Richmond, Surrey, England,
April 14, 1946

GEOMAGNETIC STORM AT ELISABETHVILLE, MARCH 28, 1946

Dr. G. Heinrichs, Director of the Elisabethville Magnetic Observatory, Elisabethville, Katanga, Belgian Congo, reported the geomagnetic storm of March 28-29, 1946, as one of the "strongest" storms ever recorded there, approximating in severity and range that of March 1, 1941.

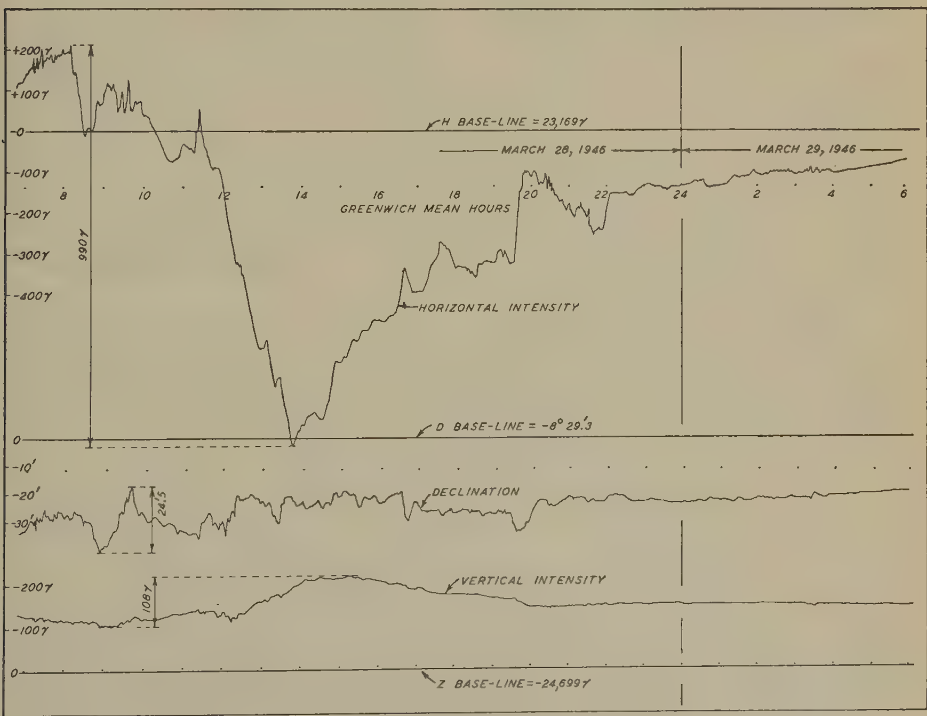


FIG. 1—REPRODUCTION OF MAGNETOGRAM AT ELISABETHVILLE, BELGIAN CONGO, MARCH 28-29, 1946 (φ=11°39.'5 SOUTH, λ=27°28.'1 EAST)

Figure 1 shows the record of the magnetic storm at the Elisabethville Magnetic Observatory. The beginning of the storm—between 06^h and 07^h—was lost because the reserve recording-spot was being adjusted at the time. Detailed accounts of the associated geomagnetic disturbance at individual

observatories appear elsewhere in this issue of the Journal. However, several aspects merit some comment.

This storm, which appeared to climax a series of smaller ones commencing on March 23, became violent shortly after 08^h GMT, March 28, with increases (within the succeeding six hours) in westerly D of $24'.5$ and in Z of 108 gammas, while H decreased 990 gammas. The greatest storm previously recorded at Elisabethville was on March 1, 1941, when ranges were: H, 976γ; D, $33'.9$; Z, 93γ.

Reports from Leopoldville, some 250 miles away, indicated that the ionized regions of the Earth's outer atmosphere were not disturbed on March 28. However, toward the end of the long recovery or post-perturbation period of the magnetic storm, there was radio-fading from $15^h\ 40^m$ to 17^h GMT, March 29. These conditions appear unusual, as in the north temperate zone and especially in the north polar region the ionospheric storm was of very severe intensity.

With regard to solar conditions existing at this period, the McMath-Hulbert Observatory reported flares on March 20, 21, 23, 25, 26, and 27 (missing days were cloudy), and on March 28 there was a large sunspot about 10° west of the central meridian with an area of about 17 square degrees. Mount Wilson Observatory rated this sunspot as active on March 24, 25, and 26 (clouds interfered prior to March 24). Coronagraphic observations at Climax, Colorado, were not obtained when the large sunspot-region passed the east limb, but the west-limb observations two weeks later showed unusual coronal activity.

Utilizing weighted mean indices K_A, this storm of March 28, 1946, is compared in Table 1 with some previous severe ones which occurred during 1940 and 1941; also for completeness indices for the disturbed day of March 25, 1946, are given.

Table 1—*Weighted mean indices K_A for geomagnetic storms*

Dates	Hours, GMT								Sum
	00–03	03–06	06–09	09–12	12–15	15–18	18–21	21–24	
March 24, 1940	4.0	4.5	3.5	3.5	7.0	9.0	8.0	6.5	46.0
March 25, 1940	8.5	7.5	7.5	8.0	6.0	3.5	6.0	6.5	53.5
March 1, 1941	3.0	5.5	8.0	8.0	8.5	8.5	7.0	5.5	54.0
September 18, 1941	2.0	5.5	7.5	8.0	8.0	7.5	8.0	7.5	54.0
March 25, 1946	6.0	5.0	6.5	7.5	6.5	7.0	7.0	6.0	51.5
March 28, 1946	5.0	4.5	7.5	9.0	9.0	8.5	7.0	6.5	57.0

From the above it would seem necessary to classify the storm of March 28, 1946, as one of the most severe in recent years.

W. E. Scott

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., April 17, 1946

TWO NOTABLE GEOMAGNETIC STORMS[1]

Disturbances of considerable intensity, comprising two distinct geomagnetic storms, occurred during the interval March 23-29, 1946. Displays of the Aurora Borealis have been reported; there was dislocation over long-distance radio channels and, in the case of the second storm, with submarine-cable telegraphy. The Astronomer Royal has given the following provisional data: Ranges in the three elements (D, H, and Z) of the Earth's magnetic field as recorded at the Abinger Magnetic Observatory during the three 24-hour intervals commencing March 23 at 11^h UT.

1946	*D*	*H*	*Z*
	°	γ	γ
March 23–24	0.9	300	180
March 24–25	0.8	230	400
March 25–26	1.5	430	510

A small abrupt movement in H at $17^h\ 16^m$ on March 23 might be taken as the beginning of this storm, which at first did not, however, increase rapidly. The Aurora Borealis was seen in Britain on each of the above nights. At 17^h on March 23, a biggish group of sunspots was nearly 50° east or four days before central meridian passage of the Sun's disk—not a favorable position for any transient corpuscular stream ejected from the spot-region to encounter the Earth.

On March 28, another disturbance began suddenly at $06^h\ 35^m$ and rose to one of great intensity within a few hours. The range in D probably exceeded $2\frac{1}{2}°$ and that in H 1500γ, but further details are awaited. The last storm of similar intensity occurred in 1941 on March 1-2, in which the D-range at Abinger was 3°.0, 1770γ in H, and $> 800\gamma$ in Z. At 06^h on March 28, the spot-group was 13° or one day past the central meridian. The connection between the spot-region and this storm seems more probable, but at present there is an absence of reports of major solar flares having been

[1]Because of the severity of the storm recorded at Elisabethville, it seemed desirable to reprint here this account which was published in *Nature* [157, 435, April 6, 1946]. In this connection see also Principal Magnetic Storms in this issue [pp. 287–301].—*Ed.*

observed with their accompanying radio fade-outs. Superficially, the recent solar conditions seem to contrast sharply with those preceding the magnetic storm of February 7-8 [see *Nature*, February 16, p. 187]. There was then the great spot near the central meridian; numerous fade-outs had been recorded, and some distinctive solar flares had been observed. Dr. J. Bartels reports that strong aurora, extending over the zenith, was seen at Göttingen, Germany, on March 28, 1946, from sunset to about 20^h GMT.

FIVE INTERNATIONAL QUIET AND DISTURBED DAYS FOR JULY TO SEPTEMBER, 1945

Reports of geomagnetic activity for the third quarter of 1945 have been received from a sufficient number of observatories so that the international quiet and disturbed days can be selected in accordance with the method outlined on pages 219-227 in the December, 1943, issue of this Journal. The selection is based on the reports of magnetic character on a scale of 0, 1, and 2 from 32 observatories and of K-indices from 28 observatories.

Month	Quiet					Disturbed				
July	10	15	20	22	27	1	4	6	17	30
August	10	18	19	20	24	2	13	14	23	28
September	10	14	15	23	24	4	12	17	18	30

W. E. Scott

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., March 27, 1946

SOLAR AND MAGNETIC DATA, JANUARY TO MARCH, 1946, MOUNT WILSON OBSERVATORY

The magnetic storm of January 3 occurred when only small sunspots were present on the Sun.

The very great magnetic storm of February 7 began when the immense sunspot-group, Mount Wilson No. 7943, the largest ever recorded (see *Pub. Astr. Soc. Pacific*, **58**, 86-88 and 168, 1946), was 2.0 days past the central meridian, its minimum distance from the center of the solar disk having been 34°. The group consisted of two large spots, each with multiple umbrae, accompanied by several much smaller spots. The over-all length was 192,000 miles. The area, which changed little during the passage of the group across the Sun, was approximately 5400-millionths of the Sun's

TABLE 1—*Magnetic Storms*

Greenwich civil time							Range in H
Beginning				Ending			
1946		*h*	*m*	*d*	*h*	*m*	γ
Jan.	3	8	10*	4	10	..	170
Feb.	7	10	20*	8	18	..	425
Mar.	1	1	39*	1	10	..	120
Mar.	10	2	53*	11	8	..	140
Mar.	22	5	40*	26	11	..	260
Mar.	28	6	34*	29	16	..	705

visible hemisphere. As seen projected on the Sun's image, the group covered almost one per cent of the solar disk. The magnetic polarities of the group were normal, but with some complications in the following spot. The umbrae of the preceding spot all had S (negative) polarity; those of the following spot (the largest single spot on record), N (positive) polarity, with the exception of the preceding umbrae and of a small umbra near the following edge. On February 6, brilliant solar flares of intensity 3 were photographed throughout the group from $16^h\ 28^m$ to $18^h\ 38^m$, GCT. A flare of intensity 3 was observed on February 11 from $00^h\ 00^m$ to $00^h\ 35^m$.

When the magnetic disturbance of March 1 began, this sunspot-group (now numbered 7978), which had again been brought into view by the Sun's rotation, was 71° east of the central meridian. Although still large enough to be seen easily without a telescope, it was much diminished in area. A "metallic" prominence was observed over the group on February 26.

When the magnetic storm of March 10 began, group No. 7978 was 44° west of the central meridian.

When the magnetic storm of March 22 began, a large complex bipolar group, No. 8002, was 70° east of the central meridian.

When the very great magnetic storm of March 28 began, group No. 8002 was 9° west of the central meridian and the great sunspot-group previously mentioned, now numbered 8006, was just coming around the east limb of the Sun on its third appearance. It was still further diminished in area, only the following part remaining. Stormy weather prevented solar observations on Mount Wilson from March 28 to 31.

TABLE 2—*Solar and magnetic data*

Day	January 1946						February 1946						March 1946					
	K_2		H_α bright	H_α dark	No. groups	Mag'c char.	K_2		H_α bright	H_α dark	No. groups	Mag'c char.	K_2		H_α bright	H_α dark	No. groups	Mag'c char.
	Whole disk	Central zone					Whole disk	Central zone					Whole disk	Central zone				
1	1	1	1	1	4	0.5	3	2	3	3	8	0	4	2	3[d]	2	11	1
2	1	0	1	1	4	0	3	2	3[d]	2	5	0	4	2	3	2	8	0.5
3	1	1	1	2	4	1	..	..	..	..	..	0.5	5	3	4[d]	2	8	0
4	..	..	..	..	3	1	..	..	..	..	6	0	5	2	4	3	8	0.5
5	1	1	1	1	2	0	3	2	4[d]	3	7[k]	0.5	5	3	4	3	9	0.5
6	1	1	1	1	1	0	4	2	5[d]	2	7	0.5	5	3	4	4	8[l]	0.5
7	1	1	1	2	2	0	4	3	4[d]	3	8	2	4	3	4	3	8	0
8	2	2	2	2	2	0	4	3	4[d]	3	6	2	4	3	4[d]	3	6	0
9	2	2	2	2	2	0	4	3	3	2	8	0	3	2	3	4	7	0.5
10	2	2	2	2	4	0	3	2	3	2	7	0	3	2	3	4	8	1
11	2	2	2	2	4	0.5	3	2	3[d]	3	9	0	3	1	3	4	6	0.5
12	2	2	2	2	2	0	3	1	3	3	10	0	2	1	3	3	6	0
13	2	1	2	2	8[b,b]	0	2	2	2	2	10	0.5	..	..	..	..	..	0
14	2	1	2[d]	2	7	0	2	1	2	2	8	0.5	2	1	2	2	5	0
15	2	1	2	2	9	0	2	1	2	2	7	0.5	2	1	2	2	5	0.5
16	2	2	3	2	6	0.5	2	1	2	2	6	0.5	2	1	2	2	5	0
17	..	..	3	2	6[i]	0.5	2	1	2	1	5	0	2	1	2	2	8	0.5
18	2	2	2	2	5	0.5	2	0	2	2	6	0	2	1	2	2	8	0
19	2	2	2	2	5	0	2	0	..	..	6[b]	1	..	..	..	..	..	0
20	2	1	2	2	5	0	2	2	2	2	6	0.5	..	..	..	..	..	0
21	1	1	1	2	5	0	2	3	3	2	7	1	..	..	..	..	..	0
22	2	1	2	2	5	0.5	2	3	3	2	7	0.5	..	..	..	..	8	0.5
23	2	1	2	2	6	0.5	2	3	3	2	10	0.5	..	..	..	..	7	0.5
24	2	2	2	2	4	0.5	3	2	3	2	10	0	..	..	3	3	6	1.5
25	2	3	2	2	3	0.5	3	1	3	1	8	0	3	1	3	3	4	2
26	2	3	2	3	2	0.5	3	2	3	1	11	0	3	1	..	..	3	1
27	2	3	2	3	3[g]	0	3	2	3[d]	1	10	0	3	1	..	..	3[j]	0.5
28	2	2	2	3	3	0	3	2	3[d]	2	11	0	..	..	..	..	..	2
29	2	1	3	2	4	0.5							..	..	..	..	..	1
30	2	1	3	2	5	0.5							..	..	..	..	..	0
31	3	1	3	3	6[a]	0							..	..	..	..	..	0
Mean	1.8	1.5	1.9	2.0	4.2	0.3	2.7	1.8	2.9	2.1	7.7	0.4	3.3	1.8	3.1	2.8	6.7	0.5

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

a, b Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

c, d Very bright chromospheric eruptions. (*c*) less than 30° from the center of the disk, (*d*) more than 30° from the center of the disk.

e, f, g, h, i, j, k, l Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

CARNEGIE INSTITUTION OF WASHINGTON,

SETH B. NICHOLSON

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1946

(*Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9ʰ 01ᵐ.3 W. of Gr.*)

January 3-4—A severe storm began sharply at 07^h GMT, January 3. Activity was moderate for the first three hours of the storm; however, at $10^h\ 30^m$ there was a marked increase in activity, resulting in an over-all change of 149′ in D, 1309 gammas in H, and 905 gammas in Z. The storm moderated at about 18^h, January 3, and the activity which followed consisted chiefly of low-amplitude oscillations superposed on small bays. At about 23^h this type of activity was replaced with larger-amplitude oscillations, which continued until the storm gradually died out at about 23^h, January 4. K-indices of 9, 7, and 8 were recorded between 09^h and 18^h, January 3.

January 23-25—A short period of moderately disturbed conditions began gradually at 20^h GMT, January 23, and continued until 03^h, January 25. The most disturbed portion of the period came between 06^h and 15^h, January 24, when K-indices of 5, 5, and 7 were recorded.

February 7-8—A major storm began gradually at about 08^h GMT, February 7. After about two hours of slow, sluggish activity the intensity of the storm began to increase. At $10^h\ 20^m$, February 7, both H and Z became very active and by $11^h\ 19^m$ H had decreased 2475 gammas, while Z had decreased 1005 gammas. There was comparatively little activity in D during this period. Immediately following $11^h\ 19^m$ both H and Z began to recover from the decrease, and during the next two and one-half hours (until about $14^h\ 30^m$) violent activity took place but with no extremely large, over-all changes. At about $14^h\ 43^m$, H again suddenly decreased 1522 gammas and at approximately the same time D increased some 229′. D recovered just before the end of the 14th hour, but it was not until the 16th hour that H recovered. After 16^h, February 7, the storm moderated to some extent; however, severe activity continued until 18^h, February 8. This activity consisted mainly of large-amplitude oscillations superposed on very large bays (especially for H). Six hours later (24^h, February 8) the storm completely died out. Three K-indices of 9 were recorded between 09^h and 18^h, February 7, and five K-indices of 8 were recorded between 21^h, February 7, and 12^h, February 8.

February 21—An increase in the magnitude of minor disturbances recorded during the preceding two days began at about 00^h GMT, February 21. This increase marked the beginning of a moderate storm which reached

a maximum between 07^h and 17^h, with K-indices of 7, 7, 7, and 6. Although the storm ended at about 19^h, February 21, the traces remained moderately disturbed for several days following this storm.

March 1—A brief disturbance of moderate intensity began sharply at $01^h\ 38^m$ GMT, March 1, and ended at about $09^h\ 30^m$ of the same day. Greatest severity occurred during the eighth hour when a K-index of 7 was recorded.

March 9-11—An extended period of moderately disturbed conditions began gradually at about 14^h GMT, March 9, and continued until about 24^h, March 11. The period of disturbance consisted chiefly of large, irregularly-shaped bays and at no time was there evidence of violent activity. The most disturbed portion of the period came between 12^h and 15^h, March 10, when a K-index of 6 was recorded.

March 23-29—A major storm began gradually at about 22^h GMT, March 23. After two hours of rather mild disturbances there was a sudden gain in intensity causing H to rapidly increase and Z to decrease. Moderately severe activity continued until about 05^h, March 24, when there came a lull with all elements recording in their normal positions. This period of little activity ended at 09^h, March 24, when there was a marked increase in storminess, and as the time passed the intensity of the storminess increased. Two K-indices of 9 were recorded between 12^h and 17^h, March 24. Again there was a lull and during the remainder of March 24 there was very little activity. At 00^h, March 25, moderate disturbances began to reoccur and the disturbances became more severe as the hours passed. By 08^h violent activity had begun, and it was during the following eleven hours that a maximum of disturbance was reached when five K-indices of 9 were recorded. At about 19^h, March 25, the storm subsided somewhat, and until 03^h, March 28, there were only moderate disturbances. However, the intensity of the storm again began to increase after 03^h, March 28, and at $08^h\ 30^m$ there was violent activity beginning to show. Between 09^h and 18^h, March 28, three K-indices of 9 were recorded. After 18^h the storm began to moderate and for the following ten hours the disturbance consisted chiefly of short-period, high-amplitude oscillations. At about 04^h, March 29, the storm finally died out.

JOEL B. CAMPBELL, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1946

(*Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h\ 07^m.4$ W. of Gr.*)

January 3-4—A moderately severe storm seemed to have its real beginning sharply at $08^h\ 10^m$ GMT, January 3, although this was preceded by a much smaller beginning, also sharp, at $07^h\ 01^m$. Short-period activity pre-

dominated at first, and later was superimposed on slower changes of relatively large range. K-indices of 7 were recorded for the fourth and fifth three-hour periods of January 3. There was no important activity after 10^h, January 4.

February 7-8—A severe storm began indefinitely near 09^h GMT, February 7. Violent activity in all the elements began about an hour later. This continued with only minor let-ups until about 12^h, February 8, when the elements began to quiet down somewhat. The storm ended at about 23^h. Throughout the storm short-period activity constituted a large percentage of the total. A K-index of 9 was recorded from 09^h to 12^h, February 7. In addition, three indices of 8, two of 7, and two of 6 were recorded during the storm. The elements became unusually quiet immediately after the storm had ended.

February 14-15—A period of moderate activity lasted from 07^h GMT, February 14, to about 09^h, February 15. The principal feature of the disturbance was a very sharp beginning at 17^h 37^m, February 14, followed by increased activity lasting for several hours.

February 20-21—Another period of moderate disturbance began at about 17^h GMT, February 20, and ended at about 18^h, February 21. The activity was mostly of the longer-period variety. A single K-index of 6 was the highest recorded during the period.

March 1—A very sudden increase of 62 gammas in H at 01^h 38^m GMT, March 1, accompanied by much smaller changes in D and Z, was the beginning and the main feature of a minor disturbance which lasted for about eight hours.

March 10-11—A disturbance of moderate severity began sharply at 01^h 52^m GMT, March 10, with an increase of 52 gammas in H and a decrease of about $9'$ in west declination. The activity which followed was moderate but not violent, with short periods predominating at first. The disturbance gradually diminished, and ended at about 24^h, March 11. Eight K-indices of 5 were recorded.

March 22-23—A minor disturbance began rather sharply at 05^h 40^m GMT, March 22, and lasted until about 10^h, March 23. The principal activity occurred during the first eight hours of the period.

March 23-29—A storm which developed into one of the severest recorded here in a number of years began rather indefinitely at about 20^h GMT, March 23. The period which followed might perhaps be regarded as several different storms, but none of them had entirely ended before the next one began. The activity became violent at about 01^h, March 24, but quieted down considerably at 05^h. The disturbance continued moderately severe until 01^h, March 25, when a new period of violent activity began, this one lasting for about twenty-five hours. At 11^h, March 26, the storm appeared to be practically ended, although minor activity continued. This became

more severe at about $02^h\ 35^m$, March 28, and became violent with a sharp beginning at $06^h\ 35^m$. The succeeding disturbance was the most violent of the entire storm. The K-indices beginning at 06^h, March 28 ,were 8, 9, 9, 9, 8, 7, 6. Earlier in the storm an index of 8, six indices of 7, and nine indices of 6 had been recorded. The storm again appeared to have ended rather abruptly at about 05^h, March 29, but at $08^h\ 35^m$ there was another sudden increase of 64 gammas in H, and smaller changes in the other elements. After this the activity consisted mostly of very short-period oscillations with small amplitudes, which became unimportant by the end of March 29. The ranges for the entire disturbed period were: D, 4° 15′; H, 2160 gammas; Z, 1080 gammas.

John Hershberger, *Observer-in-Charge*

Tucson Magnetic Observatory

January to March, 1946

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h\ 23^m.3$ W. of Gr.)

January 3-4—A magnetic storm of moderate intensity began at $07^h\ 00^m$ GMT, January 3. During the first eight hours of the storm the activity was mainly a long-period variation of D and H. From 15^h to 17^h, January 3, there were very rapid variations. For the next eighteen hours activity was slight, but with a markedly depressed H. The storm ended about the middle of the Greenwich day, January 4. Ranges: D, 21′.5; H, 197 gammas.

February 3—Following a period of exceptionally quiet magnetic conditions, at $13^h\ 44^m$ GMT, February 3, H increased sharply by about 40 gammas, with accompanying very slight disturbances in D and Z. For the seven hours following, there was only mild activity. At $20^h\ 45^m$ there was a sudden drop of 15 gammas in H, with small changes in D and Z, following which very quiet conditions again prevailed.

February 7-8—At about 08^h GMT, February 7, mild activity commenced in D. At $10^h\ 19^m$, an extremely rapid increase of 60 gammas in H ushered in a severe magnetic storm. During most of the first twenty-four hours there were rapid oscillations in the field, amounting to as much as 130 gammas in H and corresponding, large, short-period changes in D. The violent activity had died out by 12^h, February 8, and the minor fluctuations ceased about 22^h on that date, although H continued at a lower-than-normal value for some time following that. Ranges: D, 44′.25; H, 425 gammas; Z, 106 gammas.

February 20-21—A moderate period of disturbance began about 21^h GMT, February 20, and ended about 18^h, February 21. There were no outstanding peculiarities; the main characteristic of the storm consisted of long-period variations in D and H, with only very slight disturbance of Z. Ranges: D, 17′.25; H, 137 gammas.

March 1—A moderate disturbance lasting only about eight hours began

with a sharp rise of about 45 gammas in H, at $01^h\ 37^m$ GMT, March 1. Total range in H was about 135 gammas.

March 9-11—Without sudden commencement a moderate storm began about 15^h GMT, March 9. Ranges were small, with moderately rapid fluctuations, for the first twenty-eight hours. H then decreased some one hundred gammas over a period of an hour and a half, with moderate, long-period fluctuations. Most of the activity died out about the middle of the Greenwich day, March 11. Ranges: D, 13′.25; H, 147 gammas.

March 23-27—A moderately severe storm began without sudden commencement about 21^h GMT, March 23. H decreased approximately 200 gammas in the first five hours, with an accompanying rise in Z, and considerable disturbance in D. During the next twelve hours, H and Z slowly recovered normal values, but exhibited considerable disturbance in doing so. Beginning about 01^h, March 25, H again dropped to a low value, and then for about thirty hours there were moderately large, long-period oscillations in both D and H. Activity gradually decreased and the storm had an apparent ending about 06^h, March 27. Ranges: D, 28′.25; H, 225 gammas; Z, 80 gammas.

March 28-29—An exceedingly severe storm of comparatively short duration began about 02^h GMT, March 28. A sharp increase in H of 128 gammas began at $06^h\ 35^m$, requiring only about one minute in time. During the following four hours there were rapid changes in D and H, and some disturbance in Z.

At $11^h\ 18^m$ there was another sudden increase in H of about 85 gammas, accompanying a drop in east declination of 9′, following which there was a period of three hours in which changes in H and D were so rapid that some of the record was lost entirely because of failure of the recording spots to register. Within an hour's time H decreased more than 550 gammas from the maximum for the storm-period. Also, during this three-hour period of great activity, the Z-trace went off the sheet (for an undetermined minimum value of Z).

Beginning about 16^h, March 28, immediately following the period during which large ranges were recorded, there were about seven hours during which very rapid oscillations in the field occurred over moderate ranges—up to about 100 gammas in H, and about 10′ in D. Beginning at 22^h, March 28, the activity moderated; it continued as moderate until about 17^h, March 29, at which time all principal disturbance apparently due to this storm ceased.

Accurate ranges could not be determined because the upper reserve-spots of both D and H failed to record the rapid motion at the probable times of the minimum values of D and H, and the Z-trace was off the sheet at the time of minimum Z. Estimated ranges: D, 70′; H, 695 gammas; Z, 240 gammas.

C. Edward Westerman, *Observer-in-Charge*

ALIBAG MAGNETIC OBSERVATORY[1]

JANUARY TO MARCH, 1946

(Latitude 18° 38'.3 N., longitude 72° 52'.3 or 4^h $51^m.5$ E. of Gr.)

January 3-4—A storm of great intensity suddenly commenced at 08^h 07^m GMT, January 3, raising H by 44 gammas and lowering Z by 2 gammas in about six minutes. After a period of slight disturbance H began to fall rapidly at 10^h 30^m and in about ninety minutes H diminished by 256 gammas, after which there were some rises and falls both in H and Z, which resulted in one K-index of 8 and two K-indices of 7. The storm ended at about 21^h, January 4. Ranges: H, 278 gammas; Z, 43 gammas; D, 8'.7.

February 7-8—A storm of great intensity commenced at 10^h 18^m GMT, February 7. Right from the beginning and almost until the end of the storm all of the three magnets, H, Z, D, were oscillating very rapidly although the amplitude was not very great, and so the highest K-index figure obtained was 7. It gave only three K-indices of 7 and five K-indices of 6. The storm ended at about 17^h, February 8. Ranges: H, 241 gammas; Z, 57 gammas; D, 10'.7.

March 9-11—A moderate disturbance with a very indefinite beginning near 12^h GMT, March 9, continued until 01^h, March 11, with occasional sharp rise and fall, which resulted in one K-index of 6 and eight K-indices of 5 during the period of the disturbance. All of the first seven three-hour intervals on March 10 recorded the K-indices 5. Magnetograms between 12^h and 15^h, March 9, resemble that of a big solar-flare effect, usually accompanied by radio fade-outs. Ranges: H, 158 gammas; Z, 61 gammas; D, 6'.2.

March 22-26—A disturbance which started with a sudden commencement at 05^h 38^m GMT, March 22, raising H by 30 gammas and lowering Z by 8 gammas in about six minutes, continued to be moderate until about 00^h, March 24, when it developed into a great storm resulting in a number of rises and falls in all the three elements. The storm ended at about 02^h, March 26, and three K-indices of 7 and five K-indices of 6 were recorded during the intense period of the storm. Ranges: H, 420 gammas; Z, 67 gammas; D, 7'.1.

March 28-29—A very severe storm whch exceeded the maximum range limits recorded at Bombay during the last one hundred years began with a sudden commencement at 06^h 35^m GMT, March 28. In one minute H increased by 82 gammas, Z decreased by 27 gammas, and D moved towards west by 1'.3. At first all of the elements recorded rapid oscillations. From 08^h, H began to decrease rapidly with occasional upward jerks and ultimately the recording spot went off the paper at 12^h 15^m and was brought

[1]Communicated by Dr. S. K. Chakrabarty, Director, Colaba and Alibag Observatories.

back by the use of a deflector-magnet. H continued to fall until about 13^h and then began to fluctuate. H attained its maximum at 07^h 10^m and minimum at 14^h 19^m, March 28. At about 14^h 20^m, H began to increase with some very sharp rises (in one case, 216 gammas in twenty-four minutes) until about 20^h, March 28, after which all the elements continued to record small oscillations until about 17^h, March 29, when the storm can be considered as practically to have ended. The intense period of the storm was between 08^h and 20^h, March 28, during which period Z and D also recorded a number of sharp rises and falls. Such rapid changes in the elements resulted in one K-index of 9, surrounded by four three-hour intervals for which the K-indices were all 8. Ranges: H, 1041 gammas; Z, 141 gammas; D, 22′.8.

M. P. Rao, *Assistant*

Huancayo Magnetic Observatory

January to March, 1946

(Latitude 12° 02′.7 S., longitude 76° 20′.4 or 5^h $01^m.4$ W. of Gr.)

January 3—A short but very strong magnetic storm began at 08^h 07^m GMT, January 3, with a 50-gamma increase of H in six minutes, followed by almost four hours of very moderate, small movements. Then at 12^h 05^m a deep bay began with its minimum at 12^h 40^m, followed by over an hour's slow increase and then a sharp, narrow peak at 14^h 25^m and another peak at 15^h 38^m, which was the maximum of the day—367 gammas above the base-line. There was a narrow, deep bay at 16^h 35^m and a series of small, deep bays on a low in H which lasted from about 18^h to 21^h. The minimum of the day was at 19^h 43^m—96 gammas below the base-line—and the range for the day was 463 gammas. As usual, H-values for several days were below normal, and D and Z were only mildly disturbed with small, sharp movements.

February 7-8—A very strong magnetic storm began at 10^h 19^m GMT, February 7, by a 60-gamma increase of H in one minute, following a short period of faint but rapid oscillations. The storm was characterized by very rapid changes in H, approaching a vibratory character during most of its existence, and by a very large range of 702 gammas. Large, rapid movements were common, but especially from about 12^h 30^m to 16^h on February 7. The maximum recorded beyond the top of the trace at 15^h 05^m but was determined from the insensitive H-trace, and the minimum was recorded at 23^h 56^m. The storm continued with somewhat diminished force until about 16^h, February 8. D and Z were much less disturbed than H but nevertheless markedly so for this Observatory, and H recorded lower values than normal for several days thereafter.

March 10—There was a short magnetic disturbance on March 10 which

began at $01^h\ 52^m$ GMT with a sharp increase of 80 gammas in H in four minutes, followed by eleven hours of small movements. Then there were two sharp peaks followed by moderate bays in the next two hours, finally ending at about 20^h after a high peak at $19^h\ 25^m$. Both D and Z showed the sharp commencement and mild disturbance during the most active part of the storm. The range in H was 297 gammas.

March 22-25—An unusually long and strong magnetic storm actually began on March 22 with a small, sharp increase in H at $05^h\ 40^m$ GMT, which was followed for over 42 hours by small, rapid movements. The active phase of the storm began at about 24^h, March 23, by a very deep bay in the following two hours, a gradual rise to the middle of the day, after which there were a number of very sharp, narrow peaks and bays until about 17^h. The night hours of March 25 were characterized by long, slow movements, with sharper and more rapid movements beginning at 11^h, again with a number of sharp, narrow peaks and bays until about 21^h, at which time the storm ended. Values of H were very low during most of the storm, though the range was only 380 gammas. D and Z were somewhat affected during the most active parts of the storm.

March 28—A violent magnetic storm occurred on March 28 and began with a very rapid increase of 118 gammas in H in two minutes, beginning at $06^h\ 35^m$ GMT. Then there were two moderate bays in the next four hours, with the more active stage of the storm beginning at about 11^h. This lasted until about $21^h.5$, when the storm ended rather suddenly. During these ten and a half hours there were large numbers of very sharp peaks and bays with a deep low at $14^h\ 28^m$ and a high at the top of a very long peak at $16^h\ 37^m$. The range in H during the storm was 1033 gammas, and went to such low values that the fiber on the sensitive magnetograph unwound at about 12^h and remained stuck until after the storm. All measurements from that time were made from the trace of the insensitive instrument. D and Z showed very marked effects during the peak of the storm, and H-values continued low for several days thereafter.

PAUL G. LEDIG, *Observer-in-Charge*

APIA OBSERVATORY

OCTOBER TO DECEMBER, 1945

(*Latitude 13° 48′.4 S., longitude 171° 46′.5 or $11^h\ 27^m.1$ W. of Gr.*)

October 11-13—A period of minor disturbance commenced with a small positive bay at 22^h GMT, October 11, and lasted until 11^h, October 13. The principal features were bays in H during the fourth three-hour period of October 12 and the third three-hour period of October 13, giving K-indices of 5 and 4, respectively. There were only slight fluctuations on the Z-trace, and D was undisturbed.

October 23-26—A sudden commencement at 23^h 42^m GMT, October 23, followed by small irregular oscillations for eight hours, marked the beginning of a period of moderate magnetic disturbance. From 08^h, October 24, until 17^h, October 25, the disturbance took the form of irregular bays, after which the trace gradually returned to normal by 01^h, October 26. K-indices of 4 and 5 were recorded during the storm. The principal activity occurred in H, and to a lesser degree in Z.

November 9—A large negative bay giving a K-index of 5 in the third three-hour interval, GMT, November 9, followed by a positive bay in the next three-hour interval with a K-index of 4, marked a period of unimportant disturbance on this day.

December 13-14—A sudden commencement at 12^h 40^m GMT, December 13, followed by a quiescent interval for seven hours, marked the beginning of a period of moderate activity. From 19^h, H diminished gradually through 210 gammas by 09^h, December 14. Irregular oscillations were recorded for the next four hours, followed by a gradual return to normal conditions. K-indices of 4, 5, and 6 were recorded during the disturbance.

December 16-17—Minor activity was recorded on all elements between 20^h 51^m GMT, December 16, and 16^h, December 17. A K-index of 5 was recorded during the first three-hour period of December 17.

December 19-20—A period of minor activity followed a sudden commencement at 18^h 12^m GMT, December 19, and continued until 06^h, December 20. K-indices of 4 and 5 were recorded.

December 23-26—A small, sudden-commencement storm began at 16^h 16^m GMT, December 23. Interspersed with periods of quiescence, minor activity persisted until 14^h, December 26.

J. W. Beagley, *Director*

Watheroo Magnetic Observatory

January to March, 1946

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h $43^m.5$ E. of Gr.)

January 3-4—A magnetic disturbance of moderate severity began with a "sudden commencement" at 08^h 10^m GMT, January 3. At this time H increased very rapidly by 32 gammas, the westerly declination decreased by 4′.5, and Z decreased by 32 gammas. Rapid and irregular fluctuations began immediately afterwards, two periods of major disturbance being worthy of mention. Between 11^h 00^m and 11^h 30^m, January 3, H decreased by 137 gammas; between 11^h 13^m and 11^h 43^m Z decreased by 122 gammas, and between 11^h 17^m and 11^h 42^m westerly declination increased by 18′. The second period of activity was between 15^h 10^m and 16^h 10^m, January 3, when a peak appeared in the H-trace, the maximum point of which was 161 gammas above the trace before and after. Corresponding movements

appeared in D and Z. Small to moderate movements in all three elements continued until 20^h, January 4, after which the traces were normal, with the H still slightly below its predisturbance value. Ranges: D, 26′.7; H, 226 gammas; Z, 168 gammas.

February 4—The sudden "bay" shown on all three elements at about 06^h GMT, February 4, is worthy of comment. During the first phase the movement was too rapid to show on the Eschenhagen magnetogram and the following data are taken from the la Cour rapid-running magnetogram. Assuming a parallax-correction of -1^m for Z, all elements began simultaneously to move very rapidly at 05^h 58^m. During the following minute Z decreased 65 gammas, H decreased 35 gammas, and D moved 10′ easterly. During the next minute H returned to its normal value, and D and Z returned about half-way towards their normal values, being at 06^h 00^m some 4′.5 east of, and 28 gammas below, their normal values respectively. From this time the three elements moved in a slower (though still considerably rapid) "bay" which reached a maximum deviation from normal of -45 gammas for Z at 06^h 04^m, 6′.0 east for D at 06^h 03^m, and 14 gammas for H at 06^h 06^m. The three elements returned to normal fairly rapidly, all being normal by 06^h 11^m. A brief but intense radio fade-out began at about 06^h 00^m. Intense absorption lasted for only 45 minutes, although absorption was higher than normal for almost three hours. A decided effect was shown on the earth-current recorder; this recorder is of a discontinuous-record type and therefore the positions of spots depend largely on the time at which they happen to print. Recorded departures of gradient of earth-potentials from their normal values are shown below.

Time		Line	mv/km
h	m		
05	59	S	1.4 East
06	00	R	1.7 East
06	02	P	8.0 South
06	03	Q	4.7 South
06	04	S	0
06	05	R	0.9 West
06	06	P	5.5 North
06	07	Q	4.7 North

February 7-8—This was a major disturbance, chiefly remarkable for the extreme rapidity of the fluctuations rather than the range of movement, though this also was considerable. There was no definite "sudden commencement," unless a violent movement in all three elements at 10^h 20^m GMT, February 7, could be thus considered, although the traces were slightly disturbed for two hours preceding this time. Very rapid movements followed immediately; indeed, at 11^h 21^m, February 7, the H-trace reached a maximum value, 202 gammas above the mean prevailing before the

disturbance. These rapid movements continued until 12^h, February 8, except for a period between $17^h\ 10^m$ and $21^h\ 10^m$, February 7, when the fluctuations were more leisurely. The value of H (after the initial increase, which lasted until $11^h\ 30^m$), although below its normal value, was not unduly low until $23^h\ 30^m$, February 7, after which it decreased by a series of very rapid movements of large amplitude, to a minimum value at $01^h\ 27^m$, February 8, of 357 gammas below the normal value of H. The rapidity of the movements slackened after 12^h, February 8, but the traces remained disturbed until 17^h, February 8, after which they gradually resumed their normal calm. Ranges: H, 559 gammas; D, $49'.4$; Z, 309 gammas.

The Aurora Australis was reported to have been seen in the district at 18^h, February 6, but although a watch was kept at the Observatory no display was observed during the period of the above disturbance.

March 23-26—Although the traces had been slightly disturbed during the preceding day, March 22, this disturbance (moderately severe, especially in its later stages) may be said to have commenced at about $14^h\ 45^m$ GMT, March 23, when a slow movement appeared in all three elements. For seven hours after this the traces were fairly quiet, but at $22^h\ 20^m$ H began to decrease by a series of rapid movements, reaching a minimum value of 135 gammas below normal at $01^h\ 20^m$, March 24. The movements in all three elements continued to be rapid, but of fairly small amplitude until 13^h, March 24; for the next $3\frac{1}{2}$ hours the amplitudes were considerably increased. From 17^h, March 24, until 11^h, March 25, the movements were small but rapid. At $11^h\ 20^m$, March 25, the greatest activity of the storm was displayed, many of the peaks and bays being of very considerable amplitude, the most outstanding of these being at $11^h\ 45^m$, $18^h\ 05^m$, $21^h\ 10^m$, March 25, and $18^h\ 00^m$, March 26. Although the traces throughout March 26 were fairly quiet, the horizontal intensity was low until about 17^h and the normal values were not resumed until the end of March 26. Ranges: D, $33'.8$; H, 249 gammas; Z, $>$ 81 gammas.

March 28-29—This disturbance was of exceptional severity but of comparatively short duration, and began with sudden, violent movements in all three elements at $06^h\ 36^m$ GMT, March 28. The initial movements were so rapid that they did not record in their entirety on the Eschenhagen trace, but an examination of the la Cour rapid-run magnetogram indicates that H first increased by 84 gammas in 20 seconds, then decreased by 67 gammas, and increased again by 44 gammas; the net result of the movements, which altogether only occupied three minutes, was that H increased by 66 gammas. Initial movements in D and Z were equally violent. The westerly declination at first decreased by $7'$, then increased by $18'$, and then decreased (more slowly) by $17'$. Z decreased by 39 gammas, then increased by 50 gammas, and then decreased (more slowly) by 78 gammas. Violent and rapid movements continued in all three elements until, at 11^h,

March 28, the Z-trace exceeded the limits of registration and only reappeared for very brief periods until $16^h\ 05^m$ on the same day, when the value decreased sufficiently for the spot to record. So large were the movements in H, particularly between $11^h\ 20^m$ and $11^h\ 50^m$, and 14^h and 15^h, March 28, that the H reserve-spot was off the lower edge of the sheet from $14^h\ 06^m$ to $14^h\ 23^m$. The fluctuations, though still rapid, were less violent after 17^h, March 28, and after midnight were only of moderate size, although the value of H was still very low and did not regain its normal value until 23^h, March 29. The disturbance could be said to have ended at 16^h, March 29. Ranges: D, 96′.7; H, > 603 gammas; Z, > 344 gammas.

The Aurora Australis was seen on the evening of March 28 and the following notes were made: At $11^h\ 35^m$ GMT, light glow in south; at $12^h\ 15^m$ to $12^h\ 30^m$, strong rays radiating from south, changing rapidly; at $12^h\ 35^m$, a very bright, small lenticular patch was seen due south about 15° above horizon and in a minute it moved in a curve to the southwest horizon; at $13^h\ 10^m$, a bright arch spanning from southeast to southwest was first observed (this persisted until 14^h), while south of this the sky was comparatively dark; at $13^h\ 30^m$, very bright rays appeared to originate from the arch and converged to a point 10° north of zenith; at $13^h\ 45^m$, arch was still present, and in west considerable light north of west; at $14^h\ 15^m$, only glow to south.

W. C. Parkinson, *Observer-in-Charge*

Hermanus Magnetic Observatory

January to March, 1946

(*Latitude 34° 25′.2 S., longitude 19° 13′.5 or $1^h\ 16^m.9$ E. of Gr.*)

January 3-4—A magnetic storm started suddenly (H increased 30 gammas in three minutes) at $08^h\ 10^m$ GMT, January 3, and continued for about 35 hours. The ranges of the storm were as follows: H, 218 gammas; D, 31′.7 ≡ 129 gammas; Z, 185 gammas. After about 22^h the form of the magnetic activity was slow oscillations with three large bays, each of magnetic activity $K = 4$, from 15^h-24^h, January 4. The greatest magnetic activity of the storm was $K = 6$ for each of the three-hour periods 09^h-15^h, and $K = 7$ for the period 15^h-18^h, January 3.

January 23-26—Gradual-commencement disturbances, which began at about 23^h GMT, January 23, and were of moderate activity during January 24, continued until 20^h, January 26. The ranges of the storm were H, 90 gammas; D, 20′ ≡ 81 gammas; Z, 52 gammas.

February 2—A small, sudden-commencement disturbance (H increased 12 gammas abruptly) started at $01^h\ 00^m$ GMT, February 2, and was followed by minor disturbances until 12^h, February 2.

February 3-7—Abrupt changes took place at 13^h 43^m GMT, February 3. These abrupt changes were of "crotchet"-form on each trace. *H* increased 25 gammas and *Z* 20 gammas in seven minutes. The traces returned to a normal level in about seventy minutes, forming bays on the traces. After an interval of about 16.5 hours, sudden-commencement disturbances of "crotchet"-form again developed but of smaller range. Minor disturbances continued until the commencement of a large magnetic storm on February 7.

*February 7-8**—A violent storm broke out at 10^h 19^m GMT, February 7, and continued for about 35 hours. The storm began with a series of violent oscillations. The ranges of the storm were: *H*, 292 gammas; *D*, $47' \equiv 190$ gammas; *Z*, 217 gammas. The storm was remarkable more for the violence of the oscillations than for the ranges, which were about half the ranges of the storm of March 1, 1941. The largest three-hour-period activity during the storm was $K = 6$ for each of the periods 18^h-24^h, February 7, 03^h-06^h and 09^h-12^h, February 8.

February 13-17—Following a period of comparative quiet, sharp bays developed in the *D*- and *Z*-traces (68 gammas and 50 gammas, respectively) between 11^h 35^m and 12^h 10^m GMT, February 13. The effect on the *H*-trace was very small. About 17 hours afterwards, small disturbances appeared, which developed into an abrupt disturbance at 17^h 36^m, February 14. The disturbance persisted until 07^h, February 17.

February 18-22—The main features of the moderate disturbances, which began at about 16^h GMT, February 18, and continued until about 15^h, February 22, were sudden, sharp changes (*H*, 23 gammas; *D*, 5 gammas; *Z*, 17 gammas, in two minutes) at 15^h 01^m, February 19, resembling the traces of a sudden-commencement storm. The maximum *K*-values were 5 for the three-hour periods 09^h-12^h, 18^h-24^h, February 19, 21^h-24^h, February 21, and 09^h-12^h, February 22.

February 27-March 1—Following a week of minor disturbances, small kinks appeared on all traces at 06^h 25^m GMT, February 27, and again at 07^h 11^m, February 28, the changes of each being of the order $\Delta H = 6$ gammas. These kinks heralded a storm, which broke out suddenly at 01^h 38^m, March 1, and continued for about 9.5 hours.

March 1-6—Prominent among the small oscillations which occurred during this period were large bays of *K*-value 5 during the periods 06^h-09^h GMT, March 1, and 21^h-24^h, March 4, a large oscillation after 11^h 28^m, March 6, and small bays in *D* and *Z* at 08^h 58^m, March 6. The small *D*-bay shows an increase of westerly declination, and the *Z*-bay a numerical increase of vertical intensity, which is unusual.

March 9-11—Disturbances of moderate intensity, which began at about 12^h GMT, March 9, and continued until about 02^h, March 11, were characterized by sharp oscillations during the earlier stages and bays at the

*See Figure 1.

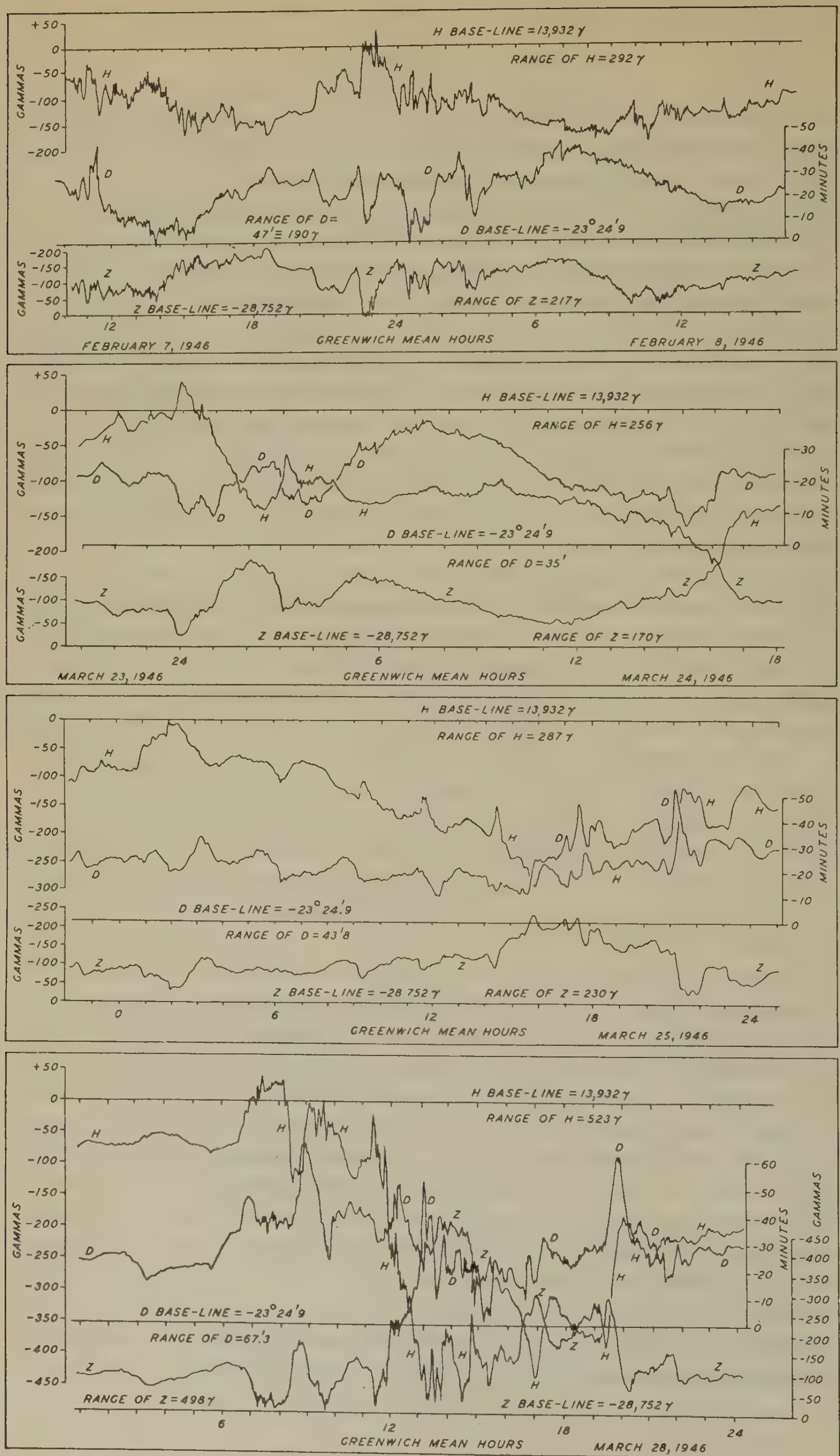


FIG. 1—MAGNETOGRAMS RECORDED AT HERMANUS MAGNETIC OBSERVATORY
(34° 25.′2 S, 19° 13.′5 E)

end. The largest K-index was 5 for the period 15^h-18^h, March 9, and also for the periods 00^h-06^h, 12^h-15^h, 18^h-24^h, March 10.

March 20-22—Minor disturbances on March 20 were followed by abrupt changes in all elements at 03^h 00^m GMT, March 21 (H increased by 30 gammas in five minutes). Similar abrupt changes occurred at 05^h 39^m, March 22. The largest K-index was 5 for the periods 06^h-09^h, 12^h-15^h, and 21^h-24^h, March 22.

*March 23-26**—A storm, which started gradually at about 18^h GMT, March 23, developed into a large storm with ranges on March 24 as follows: H, 256 gammas; D, $35' \equiv 140$ gammas; Z, 170 gammas. The storm continued up to 12^h, March 26, with ranges on March 25 as follows: H, 287 gammas; D, $44' \equiv 176$ gammas; Z, 230 gammas. The largest K-indices were 7 for the period 00^h-03^h and 6 for the periods 00^h-03^h, 15^h-18^h, March 24, 6 for the period 00^h-03^h, and 6, 7, 6, 7, for the periods 12^h-24^h, March 25.

*March 27-28**—A storm which began gradually at about 21^h GMT, March 27, developed into a violent storm with large ranges as follows: H, 523 gammas; D, $67'.3 \equiv 269$ gammas; Z, 498 gammas. The storm continued until about 16^h, March 29, ending with giant micro-oscillations. The largest K-indices were 7, 8, 8, 7, 8, 6, for the periods 06^h-24^h, March 28.

The following Table gives a comparison between the magnetic ranges of the four largest storms since January 1, 1941.

Date	Ranges		
	H	Z	D
	γ	γ	$'$
Mar. 1, 1941	614	640	85
July 4, 1941	456	293	58
Sep. 18, 1941	500	399	84
Mar. 28, 1946	523	495	67

A. Ogg, *Director*

*See Figure 1.

NOTES

11. *International Scientific Radio Union and Institute of Radio Engineers*—On May 2, 3, and 4, 1946, a joint meeting of the American Section of International Scientific Radio Union and the Institute of Radio Engineers was held in Washington, D. C. Among papers of interest to readers of the JOURNAL were the following: Electromagnetic signals produced by lightning, by S. Kass, L. A. Pick, and A. C. Trakowski, Jr.; Radar echoes from the nearby atmosphere, by M. W. Baldwin, Jr.; Detection of rapidly moving ionospheric clouds, by H. W. Wells, J. M. Watts, and D. E. George; Nomographic methods for the correlation, analysis, and prediction of ionospheric characteristics, by Marcella L. Phillips; The variability of sky-wave field intensities at medium and high frequencies, by N. Smith and M. B. Harrington; Correlation of magnetic disturbances with solar corona, by A. H. Shapley and W. O. Roberts.

12. *International Astronomical Union*—An international conference, called by the Executive Committee of the International Astronomical Union, met in Copenhagen on March 7-11, 1946. The American delegation consisted of Harlow Shapley, Otto Struve, and Joel Stebbins. Twenty-one delegates were also present from the following countries: Belgium, 1; Czechoslovakia, 1; Denmark, 1; France, 3; Great Britain, 4; Netherlands, 2; Norway, 1; Poland, 2; Sweden, 1; Switzerland, 1; USSR, 3; Vatican City State, 1. The delegate designated from Spain was absent.

The more precise determination of star positions was one of the matters considered at Copenhagen. This conference is expected to redistribute international services that were assigned to Germany, wholly in German hands, for the interwar period. It is likely that Russia will take over one or two of these service bureaus, which deal with planetary motions, with variable stars, and with the international time-services.

13. *International Meteorological Organization*—At the extraordinary Conference of Directors held at London from February 25 to March 2, 1946, it was decided to discontinue the Commission of Terrestrial Magnetism and Atmospheric Electricity and the International Commission of the Polar Year 1932-1933.

14. *Recent work at the USSR Institute of Theoretical Geophysics*—At the Institute of Theoretical Geophysics of the Academy of Sciences of the USSR, A. G. Kalashnikov has worked out a theory of the fluxmeter and a new method of studying magnetic properties of minerals. S. S. Kovner has developed a new thermal method of prospecting for minerals, and this has been successfully applied on an experimental scale in Bashkiria. V. V. Beloussev and Ronov have studied problems of geotectonic motions in the

Earth's core in connection with the history of the Earth. [From Nature, **157**, 526 (1946).]

15. *Astronomy in France during the war*—We have received the numbers of *L'Astronomie* (bulletin of the Astronomical Society of France), published from the middle of 1940 to the end of 1945. It is gratifying to note that, in spite of the great obstacles encountered by publishers during the occupation, this bulletin was issued monthly until 1944 when it was found necessary to combine four monthly issues into a single number. Important astronomical work was continued during the war. Data on solar activity—chromosphere and sunspots—during each solar rotation were observed and described in succeeding issues of *L'Astronomie*. Interesting lectures and articles summarizing our present knowledge of the ionosphere, atmospheric electricity, applied geophysics, and similar subjects appeared during this period. Auroras, zodiacal light, and other phenomena were duly recorded. The publishers of *L'Astronomie* are to be congratulated on the continuation of their important journal under adverse conditions.

16. *Institut de Physique du Globe, Paris*—We have learned from a letter of Dr. Ch. Maurain, dated March 21, 1946, that the work of the Institut de Physique du Globe of the University of Paris has resumed all its activities but that great difficulties are being encountered particularly in obtaining scientific instruments because of the unsettled industrial situation. Moreover, the prices of equipment and the cost of labor are enormously high. Much confidence is expressed in the progressive improvement of the situation but the return to normal conditions will be much slower than after the previous war during which only a part of France was occupied by the enemy.

17. *Arctic Institute of North America*—This Institute has issued its first *Bulletin* (March, 1946) entitled "A program of desirable scientific investigations in Arctic North America." In it are outlined specific undertakings which come within the range of the Institute's activities and the bulletin may be considered as a guide for its work for the next few years. Under the heading of "Mapping and description" the need of new and more accurate isomagnetic maps is emphasized and under "Special physical problems" are included ionospheric and cosmic-ray studies, terrestrial magnetism and auroral studies, and magnetic-variation stations. In addition to a broad program in geophysical research, projects are also outlined in biology, anthropology, ethnology, archaeology, and agriculture. From an inspection of this bulletin, which presents the views of authorities in various fields of research, it is clear what a vast amount of work has yet to be done in the North American Arctic.

18. *Cosmic-ray data to be collected by airplane*—For the purpose of increasing our knowledge regarding the variation of cosmic-ray intensities with latitude and altitude, the National Geographic Society, the United States Army Air Forces, and the Bartol Research Foundation will jointly

conduct a series of four round-trip flights in a specially equipped B-29 bomber. These flights, scheduled for the latter part of May, 1946, will extend between north latitude 50° and the geomagnetic equator, some 20° south of the geographical equator. The studies will be made at altitudes of 5,000, 15,000, 25,000, and 35,000 feet.

The principal apparatus to be carried in the plane, consisting of multiple banks of Geiger counters, has been designed by Dr. W. F. G. Swann, Director of the Bartol Research Foundation. The counters are so arranged that they will record only the particles which move downward vertically. Each incoming particle which actuates the counters will be recorded on a moving strip of sensitized paper. Two technicians, familiar with cosmic-ray studies, will accompany the apparatus during the flights and will develop the photographic records as the work progresses.

Measurements of cosmic-ray intensities have been made at sea-level between the latitudes to be covered in these investigations. Records of similar variations with altitude have also been made at certain points by means of balloons, notably during the stratosphere flight conducted by the National Geographic Society and the Army Air Corps in 1935. The proposed flights, however, constitute the first systematic and continuous researches at selected altitudes throughout the 70° range of latitude.

It is hoped that by sketching out the pattern of cosmic-ray intensity in a cross-section of the atmosphere extending 4800 miles northward from the magnetic equator, and reaching from sea-level more than $6\frac{1}{2}$ miles upward, it will be possible to learn more about the nature of the primary particles that enter the atmosphere and there break down into the mesotrons which are recorded by the Geiger counters.

The investigations will be carried out under the direction of Dr. Lyman J. Briggs, Chairman of the Research Committee of the National Geographic Society. The Army Air Forces' cooperation in the project is under the supervision of Major General Curtis E. Le May, and the activities of the Bartol Research Foundation will be in charge of Dr. W. F. G. Swann.

19. *Cosmic-ray expedition*—Referring to our Note 30 [Terr. Mag., **50**, p. 281 (1945)] on the cosmic-ray expedition to the Pamirs (altitude 3,860 meters) of the Lebedev Physical Institute, we present the following results as outlined in Nature [**157**, 525 (1946)]. A quantitative estimate was obtained of the number of slow strongly ionizing particles, believed to be a product of hitherto unstudied nuclear reactions initiated by cosmic rays. Slow secondary mesons have been found among those strongly ionizing particles, as well as protons. Using a new method of observation, the size-distribution of ionization-bursts caused by Auger showers was determined for the first time at great heights. As well as the usual Auger showers of electrons, "penetrating" showers, possibly of mesons, were also found but their nature is not yet clear.

20. *Apia Observatory, Western Samoa*—On December 8, 1945, the Apia Observatory reverted to the Department of Scientific and Industrial Research and J. W. Beagley assumed control as Director in place of Flight-Lieutenant H. B. Sapsford who had been serving as Acting Director and who began his demobilization leave on that date. On December 30, 1945, the latter was transferred to the Department of Scientific and Industrial Research and he returned to New Zealand early in 1946. In the future that Department will be responsible for the conduct of the geophysical activities of the Observatory. The meteorological work, however, will remain under the Royal New Zealand Air Force with Flight Officer J. H. Croxton in charge. On December 8, 1945, Dr. E. Marsden, Secretary of the Department of Scientific and Industrial Research paid a brief visit to the Observatory.

21. *Carter Observatory*—The Carter Observatory, Wellington, New Zealand, has now resumed its full activities which were considerably curtailed during the war-years. Aurora Australis Circular No. 30, which is the first of a new regular series, serves as an introduction to those which will follow and emphasizes the points auroral observers should keep in mind while observing. The next circular will contain an account of the auroral displays observed during February, 1946.

22. *Magnetic observations at Cocos Island*—The Mineral Resources Survey of the Commonwealth of Australia, by arrangement with the Air Force, has sent a party to Cocos Island (Keeling Group) to carry out a series of absolute magnetic observations there.

23. *New Honolulu Magnetic Observatory*—Rapid progress is reported on the construction of the new Honolulu Magnetic and Seismological Observatory, of the United States Coast and Geodetic Survey, in the Hawaiian Islands [see Terr. Mag., **51**, 74, 1946.]

24. *Magnetic survey around the Caribbean Sea*—William E. Wiles, Geophysicist, United States Coast and Geodetic Survey, left Washington in January, 1946, to make magnetic repeat-observations around the Caribbean Sea. His schedule calls for observations in Haiti, Dominican Republic, Puerto Rico, Antigua, Trinidad, British Guiana, Venezuela, Colombia, Canal Zone, Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala, Mexico, Cuba, and Jamaica.

25. *Magnetic publications*—The United States Coast and Geodetic Survey has issued two additional volumes of observatory results: (MO-21) "Magnetic observatory results at College, near Fairbanks, Alaska, for the Second Polar Year, October 1932 to March 1934;" and (MO-23) "Magnetic observatory results at Tucson, Arizona, for 1937-38."

The manuscript of the isogonic chart of the United States has been completed by the United States Coast and Geodetic Survey. The chart is scheduled for issue the latter part of May, 1946.

"Magnetic observations in the American Republics 1941-44" is in proof. This was prepared by the United States Coast and Geodetic Survey under sponsorship of the Interdepartmental Committee on Cultural and Scientific Cooperation.

26. *Sunspot and magnetic disturbance*—The following is from *Nature* [**157**, 187, 1946]: A considerable magnetic disturbance in the Earth's magnetic field was recorded at the Royal Observatory's Magnetic Station at Abinger on February 7-8, 1946. This magnetic storm began abruptly at $10^h\ 20^m$ GMT on February 7 and lasted for about 36 hours. It was accompanied by a display of the Aurora Borealis, obscured in the southern part of Britain by cloud. The ranges of the magnetic elements were: 1°.3 in declination; more than 500γ in horizontal force, and nearly 400γ in vertical force. The storm was remarkable more for the agitation of the traces rather than for the ranges, which have been exceeded on seven or eight other occasions during the last 11-year solar cycle, 1934-44. This magnetic storm is, with little doubt, related to localized solar phenomena of which the great spot was a notable representative. At the onset of the storm, the spot-group was about 1.9 days (= 25° of solar longitude) past the central meridian. This position of a big spot when a great magnetic storm begins is in general accord with previous statistical results such as those given by Maunder 40 years ago.

Solar observations, if available from the United States, India, and elsewhere, must be collated and compared with data of radio fade-outs. Reports of fade-outs from Cable and Wireless, Ltd., indicate with a high degree of probability that two intense solar flares occurred on February 6, the day preceding the magnetic storm. The GMT of these fade-outs ($03^h\ 30^m$, $06^h\ 20^m$, and $16^h\ 15^m$-$18^h\ 30^m$, approximately) precluded solar observations being made in England while these fade-outs were in progress.

27. *Aurora Borealis, February 7, 1946*—The following is from the *Hydrographic Bulletin* of March 2, 1946. Captain R. E. Rindge, Master, S. S. *Crawford W. Long*, reports that, on February 7, 1946, while in latitude 37° 00′ north, longitude 42° 00′ west, he observed the Aurora Borealis. Pertinent details of this observation were as follows:

"The first manifestation was a distinct red glow to the north at $21^h\ 30^m$ GMT, which disappeared at $22^h\ 07^m$ GMT. The lights again appeared at $00^h\ 12^m$ GMT, February 8, and were first observed to the north, gradually spreading from northwest to north-northeast. The principal color again was red, but this time there was also a greenish glow at the bottom with streamers of lighter green coming and going at various places, giving much the effect of searchlights. It is estimated that the glow extended upward, about 25°, and remained until $00^h\ 45^m$ GMT, at which time it faded away."

While the Aurora Borealis is a reasonably common occurrence, it is not often observed this far southward.

28. *Aurora Borealis, March 23, 1946*—The following description of the aurora of March 23, 1946, was supplied by Douglas F. Manning, of Alexandria Bay, New York:

"Beginning at twilight around $19^h\ 10^m$ as an active rayed arch, which was about half way from the horizon to the zenith from northwest to northeast, the color quickly changed from apple green to a crimson red. After about 15 minutes the red died away in the northeast and became most conspicuous in the northwest while in the north and northeast the green prevailed. This rayed arch, which also took the form of streamers and patches, soon formed a green glow all over the north and northeast with a very well-defined border. In the northeast a broad band of crimson aurora like a searchlight reached up to the zenith where a partial corona formed with streamers coming up from all directions except from the south and southwest. The remarkable feature was the sharp contrast between the green light and the red crimson so close to each other. The crimson appeared much lower than the green. All this took place between $19^h\ 15^m$ and $20^h\ 00^m$, after which the aurora died down considerably and almost disappeared with the exception of an occasional outburst of isolated rays of greenish hue which would soon die out. At $21^h\ 30^m$ there remained only a green glow in the east and northeast. The forms seen were of the types illustrated in Störmer's "Photographic atlas of auroral forms" on plates 10, 25, 26, 40, 41, 42, and 43 ending in form shown on Plate 31 in a partial corona which appeared to center just southeast of the zenith."

29. *Personalia*—Dr. *Merle A. Tuve*, Chief Physicist of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, will become Director of that Department in succession to Dr. *John A. Fleming*, who retires from active duty after over 42 years, on July 1, 1946. Dr. Fleming has been appointed as Adviser to the Institution in governmental and international scientific relations from July 1, 1946. Dr. Tuve will be the third Director of the Department, which was established by Dr. *Louis A. Bauer* on April 1, 1904. Geomagnetic research owes much of its progress in this Twentieth Century to the enthusiasm, indefatigable spirit, and inspiration of Dr. Bauer—a great heritage to his two successors and their colleagues in America and abroad.

Dr. Tuve joined the staff of the Department of Terrestrial Magnetism in 1926. He had previously served as an Instructor in Physics in Princeton University and in Johns Hopkins University from which he received the degree of Ph.D. in 1926. His special fields of scientific investigation have included sources of high voltage, transmutations of atomic nuclei, and artificial radioactivity, as well as geomagnetism. In 1925, in association with *Gregory Breit*, now Professor of Physics in the University of Wisconsin, Dr. Tuve performed the classic pulse-ranging investigation of the Kennelly-Heaviside layer which laid the foundation for the use of pulses

of radiation to detect and locate objects—the technique of radar—and has made possible notable advances in geomagnetic research. Breit and Tuve, seeking to determine the existence of the layer of ionized air in the upper atmosphere, which had been postulated by *Oliver Heaviside* and *A. E. Kennelly* in 1902, developed apparatus to transmit pulses of radiation which, reflected to their instruments, proved the existence of the ionized layer and permitted computation of its distance above the Earth. This equipment was subsequently extensively redesigned by *L. V. Berkner* and adapted to continuous photographic recording at the Watheroo and Huancayo Magnetic Observatories.

Dr. Tuve was assigned to take charge at the Department of the development of the proximity fuze from September, 1940, and was made Chairman of Section T of the Office of Scientific Research and Development. Upon completion of the developmental work and of tests with pilot models which proved the practical feasibility of the fuze, the task of taking up problems of mass production of the fuze was assigned in April, 1942, to a newly formed Applied Physics Laboratory of the Johns Hopkins University at Silver Spring, Maryland, Dr. Tuve continuing as Chairman until April, 1945, when he was made Director of that Laboratory. He resigned to return to the Department of Terrestrial Magnetism on February 15, 1946. Dr. Tuve thus carried to successful fruition one of the war's major undertakings of teamwork between civilian scientists and military men. In his new capacity Dr. Tuve, with the assistance of Dr. Fleming until June 30, 1946, will be immediately engaged in effecting the full resumption of the Department's broad program of peace-time research. It has been a happy circumstance that, during the war, many aspects of the Department's regular program could be continued vigorously because of their usefulness in the war effort.

Dr. *M. A. Tuve* and Dr. *L. R. Hafstad* were awarded the Medal of Merit by President *Truman*, presented May 31, 1946, by the Secretary of the Navy in the office of the Secretary. The citation is, in part, as follows: "Primarily responsible for the development of a major improvement in ordnance, which has proved to be a determining factor in defense of anti-aircraft action by the United States Navy, and resulted in a material increase in the efficiency of offensive action by the United States Navy against enemy air power."

Professor *Sydney Chapman*, since 1924 Chief Professor of Mathematics at the Imperial College of Science and Technology, London, has been appointed Sedleian Professor of Natural Philosophy in the University of Oxford, beginning with the Trinity term in 1946. Geophysical subjects have always occupied a great part of Professor Chapman's attention; geomagnetism has particularly interested him, his numerous papers culminating in his standard book on the subject in conjunction with Professor

J. Bartels. He has also published important papers on the ionization of the upper atmosphere by radiation and the formation of the ionosphere, the formation and vertical distribution of atmospheric ozone, and the lunar diurnal geomagnetic and atmospheric-pressure variations.

G. Heinrichs, who has been in charge of the Observatory at Elisabethville, Belgian Congo, has proceeded to Belgium where he expects to publish the results of some of his investigations. During his absence, Mr. *Herrenck* will have charge of the Observatory at Elisabethville. Mr. Heinrichs took with him CIW magnetometer-inductor 17 for use at the Manhay Observatory until new instruments can be obtained to replace those destroyed during the war.

Professor *Ch. Maurain*, former Director of the Institut de Physique du Globe of Paris, has been elected President of the French National Committee of Geodesy and Geophysics in succession to the late General *Georges Perrier.*

We learn that Dr. *B. F. J. Schonland* has taken charge of the ionospheric equipment of the station at Durbanville. According to a letter from Professor *A. Ogg*, the apparatus will be set up at Slangkop, near Cape Town, where it is expected soon to be in operation.

We are glad to inform our readers that we have received assurance that Dr. *H. P. Berlage, Jr.*, formerly of the Royal Magnetical and Meteorological Observatory at Batavia, Java, is alive and making his residence in Bandoeng, Java.

Dr. *Kurt Wegener* is reported to be well and working at the Geophysical Institute of Graz, Austria.

Professor *Perry Byerly* and Captain *C. S. Piggott* were elected members of the National Academy of Sciences at its meeting of April 24, 1946, on the recommendation of the Temporary Nominating Group on Geophysics. Professor *Sydney Chapman* was elected a Foreign Associate of the Academy on April 24, 1946.

Lieutenant Commander *Elliott B. Roberts* became Chief of the Division of Geomagnetism and Seismology of the United States Coast and Geodetic Survey on March 25, 1946. His former position as Assistant Chief of that Division was assumed by Lieutenant Commander *Samuel B. Grenell.* Captain *O. W. Swainson*, the former Chief, has been assigned as Supervisor of the Western District of the Survey, with headquarters at San Francisco [see Terr. Mag., **51**, 135, 1946].

The American Meteorological Society has announced the appointment of *Kenneth C. Spengler* as Executive Secretary, and the establishment of headquarters of the Society on April 15, 1946, at 5 Joy Street, Boston 8, Massachusetts.

Dr. *John A. Fleming*, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington was elected, on March 22,

1946, as a member in the Norwegian Academy of Sciences and Letters in its Section of Mathematics and Natural Science.

K. L. Sherman, of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, received the 1945 award of the Washington Academy of Sciences for outstanding achievement in Engineering Sciences, at the meeting of the Academy on March 21, 1946. The award was made on the basis of Mr. Sherman's work in connection with the development of instruments for measuring the elements of terrestrial magnetism and atmospheric electricity.

On February 1, 1946, *James H. Nelson* resumed charge of the Tucson Magnetic Observatory of the United States Coast and Geodetic Survey [see Terr. Mag., **50**, 328, 1945].

We have learned with great regret that the eminent German authority on terrestrial magnetism, Professor *Adolf Schmidt* of Gotha, passed away October 17, 1944. We hope to present a biographical sketch and an account of his contributions to geomagnetism in an early issue of the JOURNAL.

Captain *Robert Abram Bartlett*, Arctic explorer, author, and lecturer, died in New York, April 28, 1946, aged 70 years. He began his career in the Arctic in 1897 when he wintered with Admiral Peary at Cape d'Urville, Kane Basin. His last trip was in 1935, when he went to Northwest Greenland under the auspices of the Field Museum of Chicago and the Smithsonian Institution of Washington, D. C.

We have learned with regret of the death of Professor *Blas Cabrera*, in Mexico August 1, 1945. Formerly a professor at the University of Madrid and Permanent President of the Madrid Academy of Sciences, he is widely known for his investigations in the domain of magnetism.

We regret to announce to our readers the death at Swider, March 27, 1946, of Professor *Stanislas Kalinowski*, organizer and Director of the Swider Geophysical Observatory. Professor Kalinowski did much to increase the knowledge of the distribution of the geomagnetic elements in Poland both through survey- and observatory-work. He was a familiar figure at international scientific meetings where he represented ably the interests of his country.

We learn from Dr. *J. Bartels* that Professor *Gustav Angenheister* died at Göttingen, Germany, on June 28, 1945.

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